Technical Advisory Council
Federal Communications Commission
Summary of Meeting
December 20th, 2011

The Technical Advisory Council (TAC) for the FCC was convened for its fifth meeting at 1:00 P.M. on December 20th, 2011 in the Commission Meeting Room at the FCC headquarters building in Washington, DC. A full video transcript of the meeting is available at the FCC website at http://www.fcc.gov/encyclopedia/technology-advisory-council together with a copy of all materials presented at this meeting. In addition, all materials presented at this meeting are included in electronic form in an Appendix to this document.

In accordance with Public Law 92-463, the entire meeting was open to the public.

Council present:

Shahid Ahmed, Accenture	Gregory Lapin, Independent Consultant
Mark Bayliss, Visual Link Internet, Lc	Anthony Malone, Verizon
Vinton Cerf, Google	Paul Mankiewich, Cisco
John Chapin, DARPA	Brian Markwalter, Consumer Electronics Association
kc claffy, UC at San Diego	John McHugh, OPASTCO
Dave Clark, MIT (remote attendance)	Geoffrey Mendenhall, Harris Corporation
Lynn Claudy, National Association of Broadcasters	Jack Nasielski, Qualcomm, Inc.
Richard Currier, Loral Space and Communications	Daniel Reed, Microsoft
Brian Daly, AT&T	Dennis Roberson, Illinois Institute of Technology
Adam Drobot, Consultant	Jesse Russell, incNetworks
Tom Evslin, Evslin Consulting	Marvin Sirbu, Carnegie Mellon University
Charlotte Field, Comcast Corporation	Paul Steinberg, Motorola
Mark Gorenberg, Hummer Winblad Venture Partners	Harold Teets, Time Warner Telecom, Inc.
Russ Gyurek, Cisco Systems	David Tennenhouse, New Venture Partners
Dale Hatfield, Silicon Flatirons Center for Law, Technology, and Entrepreneurship University of Colorado at Boulder	Charlie Vogt, GENBAND
Erwin Hudson, WildBlue Communications, Inc.	Tom Wheeler, Core Capital Partners, LLC
Kevin Kahn, Intel Corporation	Robert Zitter, Home Box Office

Non-council members present:

John Brzozowski, Comcast Corporation
Laura Escobar, Comcast Corporation
Paul Mankiewich, Cisco

FCC staff attending in addition to Walter Johnston and Julius Knapp included:

Lisa Gelb, FCC
Julius Genachowski, Chairman, FCC
Dan Kirschner, FCC
John Leibovitz, FCC
Chris Lewis, FCC
Mike Mackenzie, FCC
Deena Shetler, FCC

Tom Wheeler, Chairman of the TAC began the meeting by noting a new TAC member: Charlie Vogt serving as a representative of Genband.

Tom discussed possible dates for TAC meetings for 2012. Potential dates proposed were: 3/28, 6/27, 9/25, and 12/10. September 24th was suggested as an alternative date due to a religious holiday beginning on 9/25. Conflicts with other suggested dates were discussed. It was agreed to review these dates for consensus and also to ensure that the FCC Chairman was available to attend the initial meeting of the new year as he had requested.

Each of the workgroup representatives discussed their current status. (A copy of their full presentation is attached to these minutes). Jesse Russell presented the current work of the Small Cell Initiatives work group discussing both economic benefits and enablers for this technology..

Russ Gyurek next addressed issues associated with the legacy network in transition. He noted issues raised during a workshop organized by the network transition working group held to discuss this subject on 12/6. He noted that of special concern was the expense of providing broadband to rural areas and the importance of not creating a digital divide, assuring a level playing field for all. In focusing on this, it is important to identify the needs of end users and not to assume, as is customary, the need for backward compatibility

A second workshop on 12/14, focused on this subject, drew in academics for discussion. It was noted during this workshop that the transition to the next generation network is real, is occurring now, and is being driven by market forces. It is important to focus on future needs and not legacy issues. It was felt that an important outcome of this workshop was a “brain trust” that could be referenced on future issues. Future decision making should make use of multi-stakeholder forums to gain perspective on transition issues.

Dan Kirschner, speaking for the Office of the Chairman, noted that the TAC had defined network transition as an issue for the Chairman and the FCC. He discussed the economic impact of the transition and what functionality needs to be preserved. The transition will raise anew issues of interconnection, universal service, carrier of last resort, numbering support, and transition support for existing services, etc. He noted that the FCC is undertaking study of these issues and will move forward on the challenges presented by the TAC in 2012.

The Chairman joined the meeting, wishing to extend his thanks to all work group members and especially the chairs of the working groups. He introduced Dan Kirshner as his representative to the TAC on these key issues and noted that the TAC had been charted to develop ideas the Commission can move forward on. To this point, he noted that work is in progress with an executive order forthcoming on the recommendation for use of federal property to support broadband deployment. He noted that he is looking forward to working with the TAC in 2012 and made a commitment to attend the first meeting of 2012.

Vint Cerf noted in this discussion that the transition is a global phenomenon and suggested that a focus on voice may be misleading. He also urged that the in addressing broadband needs, a focus remain on fixed broadband capabilities, which is the only solution capable of meeting any future challenge. In addition, future planning must embrace diversity in the network and seek to identify the core services we wish to move forward.

Greg Lapin noted that the transition entails change not apparent to all. He suggested an education effort to ensure the average person understand not only the new benefits of the transition but the service disjoints caused by technology differences. For example, he noted that some users may not fully understand 911 differences between legacy services and new IP based technologies that may not carry this capability.

Kevin Kahn concurred in this, arguing that we need to understand what service should constitute the infrastructure of the future. Shahid Ahmed argued that market forces should drive technology but we need to ensure that critical services are provided in this new environment. The TAC debated these points, some suggesting we realize that the future will be a break from the past, while others such as Charlie Vogt noted that services will be driven by the market, not by the FCC and that the technology transition is already underway with his customers moving rapidly to broadband and supporting market driven services including voice that his customers are offering to their end users. He argued that the transition will take longer than many people expected and suggest that it will be a more evolutionary rather than revolutionary transition.

Vint Cert noted that the future will be one of diverse services but expressed concern that a slow evolution will bring Network Address Translation (NAT) devices strongly into the network, adding long term complexity. A quick transition is important to avoid this.

Dennis Roberson presented on the Spectrum Sharing Work Group. He noted the work group has developed a white paper which he hopes will serve as a living document, evolving over time. He urged that the work group continue through 2012 and indicated that future work should focus on spectrum efficiency on a macro level, as well as on the efficiency of spectrum allocation. In addition, obstacles to operationalizing the targeted

500 MHz of new spectrum should be overcome and new untapped wireless applications should be encouraged.

Charlotte Field summarized the work of the IPv6 workgroup noting that a benchmarking white paper had been developed and that members were working with the NTIA on a 1Q workshop for IPv6 Status, Policy and Benchmarking. The work group urged the FCC to raise awareness of IPv6 issues to a national level.

Paul Mankiewich suggested that for 2012, some exploration of cloud services should be undertaken. Tom Wheeler suggested that this be conducted as a voluntary effort by members and not be undertaken for the present as a formal part of the 2012 work program.

After discussion, Tom Wheeler proposed as objectives for 2012:

- Continuation of the work on IPv6
- PSTN Evolution – as tasked by the OCH as represented by Dan Kirschner
- Spectrum Workgroup Issues
    - Macro level issues on spectrum efficiency including receivers
    - Overcoming obstacles to operationalizing the 500 MHz of Spectrum
    - Framework for assessing spectrum usage
    - Security in IP wireless networks
    - Supporting untapped wireless applications

Tom's proposal for the 2012 work program was accepted by consensus.

The meeting was adjourned at 4:00 PM.

Walter Johnston, Chief/ECD
FCC

Technology Advisory Council

Meeting

December 20, 2011

TAC 2012 Organizing

- Continuing Members
- New Members
- 2012 Working Group Organization Process
- TENTATIVE 2012 Meeting Dates:
  - March 28
  - June 27
  - September 25
  - December 10 or 18

Small Cell Technology Forum
FCC Workshop
10/28/2011

The FCC TAC Small Cell Forum

- **Panel #1: Small Cell Technologies**
  - *Rupert Baines, VP Marketing, Picochip*
  - *Keith Kaczmarek, VP/GM Global Wireless Solutions, Powerwave Technologies*
  - *Steven Glapa, Senior Director of Field Marketing, Ruckus Wireless*
  - *Jim Seymour, Senior Director of RAN Strategy, Alcatel Lucent*
  - *Jay Weitzen, VP Technology, Airvana*

- **Luncheon Speaker**
  - *Ed Cantwell, SVP West Wireless Heath Institute*

- **Panel #2: Business Opportunities and Challenges**
  - *Robert Juliano, VP and CIO, Brandywine Realty*
  - *Lyn Lansdale, VP Strategic Business Services, Avalon Bay*
  - *Tormod Larson, VP & CTO, Extenet Systems*
  - *Steve Lilley, Wireless Practice Manager, Presidio Networked Solutions*
  - *Tom Nagel, VP Wireless, Comcast*
  - *Iyad Tarazi, VP Network Engineering & Development, Sprint Nextel*

- **Panel #3: Policy Directions**
  - *Brian Daly, Director, Core Standards, AT&T*
  - *Russ Gyurek, Office of the CTO, Cisco Systems*
  - *Paul Mankiewich, Chief Architect, Global CTO – Service Provider, Juniper Networks*
  - *Dennis Roberson, Vice Provost, Illinois Institute of Technology*
  - *Jesse Russell, Chairman & CEO, INC Networks*

Estimated Attendance:

[X] in person

[Y] via webcast

FEDERAL COMMUNICATIONS COMMISSION • USA •

FCC TAC Small Cell Initiative Summary and Recommendations

Potential Economic Benefits

- *Improved Broadband Wireless Coverage and Capacity within Buildings*
- *Potential Service Cost Reductions and Improved Network and Device Performance (speed, reliability)*
- *Reductions in Power Consumption (devices, network)*
- *Potential Spectrum Efficiency Improvements*
- *Potential Job creation (engineering, production, installation)*

Key Enablers

- *American Technology Leadership (e.g., SDR, SON, SoC)*
- *Standards Global Convergence (LTE, Wi-Fi)*
- *Real Estate Industry Backhaul Network infrastructure Sharing (e.g., Building Riser Facilities, Fiber Facilities, Back-up Powers Systems, etc.)*
- *Potential Availability of New Spectrum Allocations*

Key TAC Actionable Recommendations

- *Industry-Led Deployment of Universal Small Cells in Existing Licensed Cellular Bands in Buildings*
- *Commission Should Allocate 100MHz of Dedicated Spectrum for Small Cell Networks in 3550MHz -3650MHz (NTIA "Fast-Track" Band)*

The Telephone Network in Transition
FCC Workshop
12/6/2011

Focus of 12/6/2011 workshop: Rural services, disability access, transition of critical services (medical, alarms), and reliability relating to emergency services

All technology options should be utilized for rural areas, including satellite. Rural should have equal, or same service availability as urban markets

Rural will need funding and incentives- the National Broad Band plan is a great step in this direction
The only way to solve the Rural deployment issues will be through partnerships

Rural has much larger cost for middle mile and last mile
- 400-800 X for middle mile
- Interconnect is big cost
- Review on interconnect in greatly needed, VoIP is a voice service, correct?

The Disability access services are migrating quickly to IP based networks and new technologies
- TTY usage declining quickly in terms of usage per month
- DA needs will increase as Americans citizens age (boomers)
- Also, more with other languages than English as a first language
- Communication to this community is critical
- Not so much interested in the underlying technology, but the capabilities to communicate and reach needed services
- Concerns on voice quality, and battery back-up/powering. Lots of embedded legacy equipment
- Support: who to call when moving from one service provider to many options
- Trust
- Some are either unable to learn or have severe conditions that prevent them from making changes easily
- As we make changes they must be understood and acceptable…tactile keys

Standards play an important role in transition

The vast array of new services on the new IP network clearly out weighs the PSTN
- Mobility
- Apps for the Blind

How much backward compatibility is needed?

Communication and Education are key: an opportunity to work together to make the transition a success

Focus of 12/6/2011 workshop: Rural services, disability access, transition of critical services (Medical, Alarms), and reliability relating to emergency services

- Consumer market has been transitioning
  - Decline in wireless PSTN handsets, Fax Machines, and Answering machines
- Great opportunity for collaboration with trade groups during transition
- May need to have a bucket of money set aside for the transition- plan for surprises
- Avoid a tower of Babel outcome; interoperability should be the goal
- FCC should facilitate and promote Industry to take lead
- Infrastructure issues (pole attachments, RoW, etc) need reviewed for smooth transition
- Much of the outside plant infrastructure can be reused for Broadband services (being done)
- Concern on consumers having to create and manage their own networks- becoming more complex.
- Alarm/Security already having to transition to meet customer needs
  - However, many, many legacy (PSTN) based devices are in the network, there is a cost to transition

- Conclusions:
  - The FCC needs to facilitate the transition
  - Education and Communication are key
  - All groups are interested in partnering, in proactively being part of this transition

CLT-WG

The Telephone Network in Transition
FCC Workshop
12/14/2011

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Report on Telephone Network Transition Workshop (Dec. 14, 2011)

Participation and Coverage

•Excellent job by FCC staff of assembling strong panels of academic and industry representatives
•Less detailed recommendations and economic data than we would have been liked (not unexpected).
•Panelists likely to conduct research, collect and provide recommendations to the FCC over the coming year.

Comments on the Transition (what is happening and likely to happen)

•About 1/3 of households have already dropped wire-line PSTN; wireless subscriptions are about 3x wire-line.

- Disagreement among panelists on whether or not the ILECs will remain viable.

•Consensus that use of voice over analog and/or TDM equipment is going away. Less clarity on role of SS7.

•Numbering plan will continue to exist but governance and allocation process needs to be reconsidered.

•Accessibility: Packet/broadband services create new opportunities but the transition will be difficult

•Some expressed concerns over VoIP quality of service (QoS); Others noted that IP-based QoS is being achieved, citing HD-voice and managed VoIP.

Report on Telephone Network Transition Workshop (Dec. 14, 2011)

Comments on the FCC's Role in the Transition

- Focus on the future: Say more about what we are transitioning to (vs. the "sunset") to get energy and enthusiasm around the transition.
- FCC should step back and identify the social goals/needs that led to the current system of regulation and then work out which of those goals are still valid and how they will be carried forward into the future.
  - Disagreement among panelists on need for continued regulation of PSTN
  - New regulations (if any) should be agnostic with respect to specific technologies (e.g., IP).
  - Concerns over broadband access duopoly; broadband wireless could be important in this regard
- Convene multi-stakeholder forums. Get voluntary consensus where possible; FCC as a backstop.
  - Develop the "punch list" of the many "corner cases" (fax, alarms, etc.) and chart plans for them.
  - Need a plan for interoperability/interconnection amongst non-PSTN voice services (without PSTN backstop).
- Considerable support for a "flash cut date" to drive progress on the punch list
  - minority view: transitions take a long time and co-existence may persist for decades

PSTN Transition

12/20/11

Daniel Kirschner, FCC

PSTN Transition

The PSTN is in transition as more and more consumers each year decide to forgo PSTN fixed voice in favor of alternative communications technologies.

PSTN Transition

- The TAC and the CLT Working Group have done excellent work informing the FCC on PSTN transition. They have:
  - Defined the issue and highlighted it as a core concern for the FCC
  - Recommended a time horizon
  - Raised a series of key questions
  - Provided a set of recommendations for how the FCC should proceed

PSTN Transition

- The FCC has
  - Committed personnel to the issue
  - Held a series of workshops discussing issues raised by the transition (with the assistance of the TAC)
  - Considered the issue in the context of ongoing FCC actions, including rulemaking

PSTN Transition

- As we consider concrete next steps, we need to understand
  - The state of the market and how it is shifting
  - The policy implications of preserving or adding functionality in the replacement network
  - The technical challenges of preserving or adding functionality in the replacement network

PSTN Transition

- Market Analysis
  - PSTN and fixed voice projections
    - What will fixed voice demand be in the next few years and how much of that demand will be served by PSTN?
  - Economic significance of PSTN market loss
    - What is the feasibility and cost of continuing service?
    - How does PSTN market loss impact separate copper loops (e.g., DSL and alarm circuits) and voice service?
  - Market makeup of replacement technologies
    - As consumers abandon the PSTN for voice, what are they using to replace its functionality (wireless, managed VoIP, OTT VoIP, etc.)?

PSTN Transition

Technical & Policy Issues

- Challenges created by the transition away from the legacy PSTN
  - Promoting competition
  - Universality & Carrier of Last Resort obligations
  - Services that depend upon the PSTN
  - Reliability, continuity, and accessibility
- Transition away from the legacy PSTN must be analyzed from the perspective of the various stakeholders, including ILECs, CLECs, and consumers.

PSTN Transition

Technical & Policy Issues

- Capabilities of the PSTN-replacement network: What functionality should/will be preserved or added?
  - Resiliency/reliability
    - 48V power at CPE, route diversity, network elements, etc.
  - Advanced communications services
    - HD voice, video conferencing, SMS/MMS text, etc.
  - Accessibility
  - 911
  - CALEA and homeland security
  - Privacy and personal security
  - Support for existing non-voice technologies that rely upon the PSTN
    - Fax machines, alarm systems, etc.

PSTN Transition

Technical & Policy Issues

- Network interfaces and infrastructure for the PSTN replacement network
  - End user to network
    - What replaces RJ11?
  - Network to network interconnection
  - Services interconnection
  - Numbering
- Both physical interfaces and protocols

PSTN Transition

Technical & Policy Issues

- Timing of transition
  - Cutover or gradual displacement
    - Like DTV or like IPv4 to IPv6?
  - Continuity of service
  - Dependencies of steps and their timing

PSTN Transition

Technical & Policy Issues

- Universal service
  - Carrier of Last Resort
  - Eligible Telecommunications Carrier
- Competition
- Consumer education and outreach
- Preservation of critical services
- Regulatory review
- Quality of Service

PSTN Transition

Working with the TAC

- As the FCC navigates these issues, it will depend upon the TAC to provide technical advice and inform FCC analysis of policy issues.
- We are in the process of formulating technical questions to present to the TAC Working Group.
- Examples of four broad categories for which we will seek technical guidance:
  - Interconnection
  - Robustness
  - Transition of PSTN non-voice technologies
  - Numbering

PSTN Transition

Working with the TAC—Example Questions

- Interconnection
  - How does IP interconnection differ from TDM interconnection, including the economic and technical principles determining the efficient number and points of interconnection?
  - What technical standards are necessary for IP interconnection of voice in order to ensure quality and reliability, including call completion, and security (caller-ID trustability)?
  - What is the feasibility of technical standards for interconnection of services beyond basic voice (HD voice, video conferencing, text)?

PSTN Transition

Working with the TAC—Example Questions

- Robustness
  - What are current best practices for power-outage robustness for IP-based networks and have these been widely implemented?
- Transition of PSTN non-voice technologies
  - What are the major non-voice TDM-based technologies, and what are the successor technologies on IP-based networks?
- Numbering
  - What are the technical challenges and advantages in improving the numbering system?

Technical Advisory Council

Critical Legacy Transition Working Group (CLT-WG)

DECEMBER 20, 2011

Washington, DC

Meeting Agenda

- Progress since September TAC meeting
- Telephone Network in Transition – Workshop 12/6/2011
- Telephone Network in Transition – Workshop 12/14/2011
- Recommendations
- TAC discussion

Working Group Membership

- **Shahid Ahmed** - Accenture
- **Nomi Bergman** - Bright House Networks
- **Lynn Claudy** - National Association of Broadcasters
- Brian Daly – AT&T
- **Adam Drobot** (Co-Chair)
- **Tom Evslin** – Voice on the Net Coalition
- **Lisa Gelb** - FCC
- **Russ Gyurek** – Cisco
- **Greg Lapin** - American Radio Relay League (ARRL)
- **Christopher Lewis** – FCC
- Paul Mankiewich - Juniper
- **Jack Nasielski** - Qualcomm
- **Roberto Padovani** - Qualcomm
- **Andrew Setos** – Fox
- **Doug Sicker** - FCC
- **David Tennenhouse** (Co-Chair) New Venture Partners LLC
- **Bud Tribble** - Apple
- **Robert Zitter** –HBO

Progress Since September TAC Meeting

We have continued to hold a meeting of the Critical Legacy Transition Working Group at least weekly.

The focus has been preparation for the two workshops held by the FCC on Sun-setting the PSTN. We will be presenting brief summaries of the workshops today.

We have also continued to further refine what we mean by Sun-setting the PSTN and what the key elements of the transition entail.

Finally, we have also refined the recommendations to the FCC

Sun-setting the PSTN

What we had previously recommended

When we last reported in September about Sun-setting the PSTN what we meant is:

1.The orderly transition from the PSTN's role as a " system of record" for achieving key national goals

2.The identification of, and migration to, alternative mechanisms of achieving the subset of those goals that remain important to our society and economy.

3. This may or may not lead to the withdrawal by service providers of specific PSTN technologies and/or services

What will be Sunset?

Three aspects of the PSTN are relevant to the "sunset" discussion. These will not necessarily "go away" but they will no longer, on their own, constitute a universal service:

1.Facilities that support telephony and related services (fax, modem, etc.) using circuit-switching, either based on a traditional 4 KHz analog channel or its emulation via digital sampling and time division multiplexing (TDM). Examples include the telephony-specific portions of local loop line cards and multiplexing and switching equipment deeper within the network. The local loops may continue to be used to provide other services, such as DSL.

2.The protocols and mechanisms that support switch interconnection both within and between telephony service providers. Although the current signaling system (SS7) may continue to be used, its role in facilitating universal interconnection is likely to atrophy and eventually disappear.

3.The body of policies and regulations that is grounded in the assumption that there is a high degree of penetration of traditional circuit switched voice services throughout the country.

Recommendations:

The PSTN is a voice centric network which no longer satisfies all of the interactive communication needs and demands of the citizens of the United States. The transition opens many opportunities for new and richer communication capabilities. It is the technical opinion of the Critical Transition working group that market forces will lead to a significant loss of PSTN utilization by 2018 in preparation for which decisions need to begin today. We consequently recommend the actions summarized in the next few pages:.

Recommendations:

1.Develop a detailed plan for an orderly transition from the current PSTN system of record to a service rich network for achieving key national goals. The plan should include:

1. A public-private partnership with industry, providers, and relevant organizations and stakeholders.
2. Coordination mechanisms for the ongoing evolution of the network to rapidly incorporate new technologies and capabilities.

2.Establish a task force to conduct a thorough policy and regulatory analysis and review as it relates to the PSTN which results in policies for the new communication environment (Interoperability, Interconnect, E.164, numbering, reliability,…).

3.Identify mechanisms and a migration plan for critical services currently provided by the PSTN. Therefore, ensuring that critical services that need to be carried forward are met by well understood solutions. (E911, Disability access,…)

Recommendations:

4.Commit to ensuring ongoing universal access to evolving communication services to enable all Americans to participate in the nation's economy.

5.Investigate the need for the use of incentives to accelerate the transition to new services.

6.Create a communications and outreach program to educate the public about the transition.

1. Provide the public with the vision of what we are transitioning to: New services and capabilities which can greatly exceed the current services of the PSTN

2. Provide a roadmap and communicate the urgency to take action to avoid the loss of capability to support critical services.

Note:

The term “sunset” does not force providers or consumers not to use PSTN equipment or technologies; however, the sunset removes the policy and expectations from the PSTN. As a consequence of the rate at which the PSTN is naturally atrophying, it will no longer be able to serve the Nation is achieving social and critical functional goals. If we do nothing, we will end up with a deep loss of national capabilities. Accelerating the transition will mitigate these issues proactively. The transition will put the United States on a continued course of technical leadership and innovation in communications.

- TAC Discussion

Technological Advisory Council

Sharing Working Group

20 December 2011

Charter

The purpose of the Sharing Working Group is to identify steps the FCC might take to promote near term private investment and job creation based on sharing techniques, including sharing of spectrum, facilities, or other techniques as the working group may find appropriate.

Statement of Work - Focus Topics

- Spectrum Efficiency Metrics
- Receiver Standards
- Commercial Wireless Applications
- Hybrid Systems
- Emerging Technology Promotion / Deployment
- Additional Topics to be Identified by the Working Group

Working Group Members

- Peter Bloom
- John Chapin
- Richard Currier
- Brian Daly
- Dick Green
- Dale Hatfield
- Geoffrey Mendenhall
- Dan Reed
- Jesse Russell
- Paul Steinberg
- John Leibovitz
- Julie Knapp
- Dennis Roberson
- Strong support from:
  - Tom Wheeler
  - Walter Johnston
  - Chris Lewis
  - Charles Mathias

Ideas for Consideration

1. Develop Spectrum Efficiency Metrics
2. Encourage Receiver Standards
3. Create Spectrum Sharing Taxonomy
4. Accelerate Small Cell Deployments and Spectrum Sharing - especially Indoors
5. Remove Application Friction Points

Idea #1,2 &3: Spectrum Efficiency
System and Over-all

Status – Longer Term Opportunity (Short Term Implications)

Problem

- The spectrum efficiencies achieved by wireless systems individually and collectively must improve if the Nation is to accommodate rapidly increasingly demand and stimulate job growth
- There is no single measure of spectrum efficiency that can be applied across all services

Proposed Idea

- Metrics can (and have been) developed that allow efficiency comparisons to be made **between similar types of systems which provide similar services**. (e.g., bps/Hz/km^2 for personal communications systems)
- Our initial taxonomy of similar systems: Satellite Broadcast Systems, Point-to-point Satellite Systems, Terrestrial Broadcast Systems, Terrestrial Personal Communication Systems, Terrestrial Point-to-point Systems, Terrestrial Hybrid Systems – Public Safety / Utility, Radar Systems, Passive Listeners.
- The metrics should stimulate **technical efficiency -** the inherent efficiency of the modulation schemes, etc. and **operational efficiency -** the efficiencies achieved through the practices of service providers and users (e.g. through dynamic loading/sharing)

Spectrum Efficiency

Progress

- Created an integrated White Paper merging the results of three related work areas:
  - Spectrum Efficiency Metrics: Metrics developed that allow efficiency comparisons to be made between similar types of systems that provide similar services (e.g., bps/Hz/km2 for personal communications systems)
  - Receiver Standards: Rationale and approaches for incorporating receiver standards into measure of spectrum utilization
  - Spectrum Sharing Taxonomy: Identification of successful examples of sharing and proposals for co-existence opportunities
- Obtained review and feedback from full TAC and industry experts
- Established White Paper as living document that describes best practices for evaluating spectrum efficiency and provides direction for continuous improvement and improved sharing
- Draft document provide to PCAST Working Group (six month study on spectrum efficiency and technology policies)

Spectrum Efficiency

Economic Impact - Should stimulate the creation of high paying jobs and benefit the standard of living for US citizens

- Research and development on transmitters and receivers meeting ever improving specifications
- Efficient production resources for the manufacturing of this equipment
- Deployment resources needed for replacement of outdated and highly inefficient equipment
- Enhanced spectrum utilization at both the discreet system and at the over-all allocation level will free more spectrum allowing exciting new wireless application to be more rapidly deployed

Spectrum Efficiency Metrics

Actionable Recommendations

- Recognize product / service providers for leadership and encourage demonstrated progress against the metrics
- Encourage increased sharing among identified opportunities and through creation of a new sharing licensing class
- Encourage higher efficiency at the allocation level by measuring the efficiency impact of the allocation
- Engage the academic / business community in identified research topics to further vet the category and metric definitions
- Require a combination of market-based incentives and appropriate regulatory mechanisms to stimulate progress towards increasing spectrum utilization efficiency, allocation efficiency, and sharing based on the spectrum efficiency metrics and other relevant criteria.
- Coordination with NTIA / other government agencies will be required to encourage research into advanced methods for improved efficiency and to create positive incentives to encourage efficiency

Idea #4: Encourage Small Cell Deployment

Status – Near Term Opportunity - existing spectrum; Mid- to Longer-Term Opportunity where new spectrum development is required

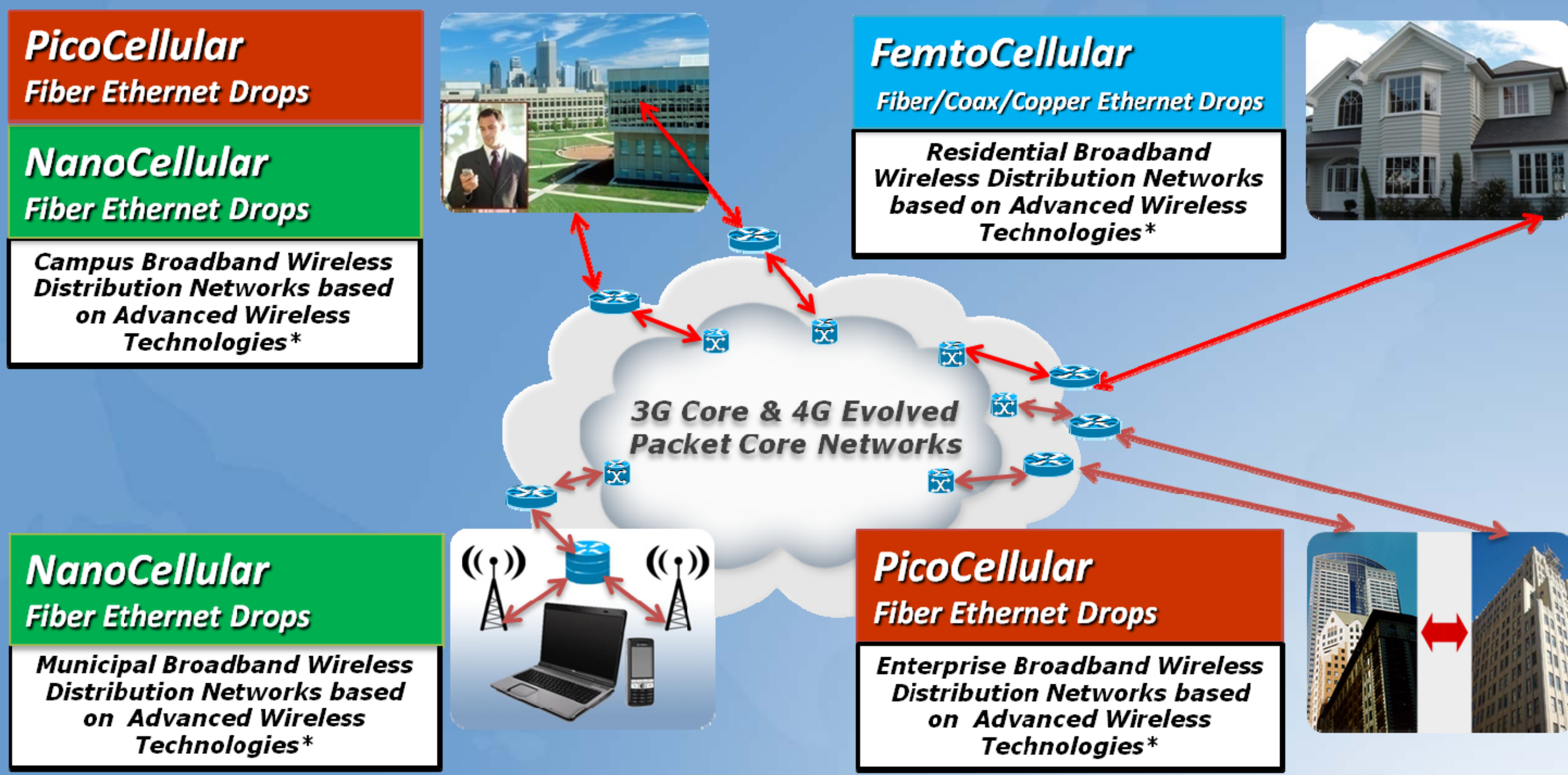
Problem

- How to accelerate deployment of fast, reliable integrated narrowband / broadband wireless solutions (e.g. Femtocells, PicoCells. NanoCells, Wi-Fi, DAS, etc.) to meet the breadth of demand for broadband services within high teledensity areas and to support new approaches of offloading high use spectrum (e.g. Wide Area Cellular Networks)
- Challenges include siting (i.e. nondiscriminatory access to venues and rapid review and approval), interference, QoS, incentives to deploy new small cell networks and the sharing of existing / new backhaul infrastructure

Proposed Ideas

- Explore mechanisms, working with federal agencies, to expedite siting requests within federal lands and buildings
- Provide spectrum assignment/allocation for carriers, premise owners, and/or third party entities to install and operate in-building networks, including "provider agnostic" infrastructure

What are Small Cell Networks?



*3G/4G LTE/4G LTE-A

FemtoCellular Networks: "Home"… Broadband Wireless Networks

PicoCellular Networks: "Buildings"… Enterprise Broadband Wireless Networks

NanoCellular Networks: "Neighborhood & City-Wide" … Community Broadband Wireless Networks

Major Small Cell Activities in US Today

Neutral Host Distributed Antenna Systems (DAS)

- ***DAS Extend Existing Wireless Provider Networks***
- ***CRMS Providers interconnect at a Central Point***
- ***Deployable by Premises Owners or Third Parties***

Wi-Fi Offload

- ***Unlicensed Wi-Fi Networks Used to Off-Load Data Traffic***
- ***No Interference Protections***
- ***Loose or No Interconnection with Existing Cellular Provider Networks***
- ***Deployable by Premises Owners or Third Parties***

The Major FCC TAC Small Cell Initiative Actionable Recommendations

Actionable Recommendation 1: Wireless Providers Deployment of Universal Small Cells in Existing Cellular Bands in Buildings

Leadership: Wireless Providers

- *Single device, software configurable to multiple provider networks*
- *Use existing licensed spectrum allocations*
- *Designed / adaptable to provider requirements*
- *Deployable by end-users or third party installers*
- *Backhaul to Wireless Providers infrastructure (Needs Further Study)*

Actionable Recommendation 2: Dedicated Spectrum Allocation of a 100MHz for Small Cell Networks in 3550MHz-3650MHz (NTIA "Fast-Track" Band)

Leadership: FCC & NTIA

- *Allocation of a New Band for Low-Power, Small Cell Applications*
- *Could Use Variety of Spectrum Management Approaches, Including Licensed, Licensed Light or Unlicensed) Interference Protections, Possibly Novel Licensing Concepts (e.g., assign to premises owners)*
- *Network Deployed and Managed by Premises Owners or Third Parties*
- *Devices Roam to New Band Based on Existing Standards*
- *Integration into Existing Devices and Systems (Needs Further Study)*

Idea #5: Reducing Application Friction Points

Status – Short and Longer Term Opportunities

Problem

- Friction Points are viewed as inhibitors to enabling public and private applications to be developed and deployed on wireless carrier networks. Public and private applications include:
  - Utilities (electric, gas, water, …)
  - Enterprise (education, energy/natural resources, healthcare, manufacturing, professional & consumer services, retail/hospitality, telecom/media, transportation/logistics, wholesale …)
  - Public Safety (police, fire, emergency services, …)

Idea

- Reduce / eliminate applications and usages barriers in a realistic , cost-effective manner: Privacy, Security, Robustness, Geographic Coverage, Survivability & Disaster Recovery, Certification.

Idea #5: Reducing Application Friction Points

Progress

- Completed SME Interviews: Carriers, Entrepreneur, Selected Verticals and Work Group knowledge base
- Tentative Friction related findings to date
  - Future (Carrier) Network Interfaces and Certification of Applications that use them
  - Platform Variation (Operating System and Underlying Hardware Capabilities)
  - Dependence on a complete ecosystem of Open Source tools / building blocks
- Need for accessible common services (mapping, speech recognition,…)
- Completed a Draft White Paper
  - Assessed Wireless Application Environment
  - Identifies Potential Opportunities
  - Offers Recommendations
  - Suggests Next Steps

Application Friction Points – Key Findings

- The nature of application development has shifted to emphasize 'mobile-first'.
- Wireless Networks: More Complex Model than Traditional Fixed Application Ecosystem
  - Relative to traditional fixed networking environments, a higher bar is imposed on mobile applications operating on wireless carrier networks (device certification - carrier network / application certification by application stores).
  - The mobile network plays a much larger role in application development than in past, fixed, environments. Important to standardize common network services (existing / new) across carriers / network technology epochs (e.g., 3G to 4G).
  - Mobile wireless carriers have advanced and offer diverse application developer platforms, forums and services. These need to be more richly publicized and utilized.
- Mobile Wireless Platforms: Diversity, Rate of Change & Lack of Common Platform Standards
  - Multiple operating system environments create a barrier, especially for native mode applications, requiring multiple ports, and increasing complexity and variability.
  - Lack of standardization/consistency in device platforms creates porting and support issues for applications. Problem is escalating as intrinsic capabilities of devices grow driving greater application complexities.

Application Friction Points – Key Findings

- Application Building Blocks: Pivotal Enablers for Entrepreneurs
  - Application developers rely on common (often open source) software building blocks, tools, and services to derive their solutions. This software is constantly evolving and the emergence of components that are widely adopted is somewhat happenstance.
  - Increased standardization or normalization for network services, operating system environments, and device platforms can also benefit the efficient production of building blocks
- <u>No 'Smoking Gun' / Focused Opportunity for immediate action to generate short term change!</u>

Application Friction Points – Recommendations

- Sponsor a mobile application developer conference –
  - Cross industry representation (carriers, entrepreneurs, specific application verticals, academia, device manufacturers, operating system suppliers, …)
- Encourage the formation of community of interest group(s) that can drive standardization (existing / new)
- Encourage carriers to establish common practices / set of network interfaces –
  - Stability for application developers
  - Common certification methods / practices to ensure that layers of certification (multiple network operators, application stores, etc.) aren't unduly imposed.
- Commission a user-community led analysis of key building blocks
  - Identification and prioritization of blocks missing today or required in the future.
  - Identification of funding sources and administer the funding for creation and/or establishment and operation of key capabilities and services.
- Next-step: Conduct a focused 'friction point' analysis of key vertical industries, (e.g. critical infrastructure/utilities, public safety, health care…) that could highly leverage wireless infrastructure.

FEDERAL COMMUNICATIONS COMMISSION · USA ·

Technology Advisory Council

Broadband Infrastructure Deployment Working Group

Working Group Overview

Charter

- Identify steps advancing the deployment of broadband infrastructure by removing impediments and providing logistical incentives.
- Focus on promoting near-term private investment and creating private-sector jobs.

Members

- Mark Bayliss, Visual Link
- Richard Lynch, Verizon (Chair-Retired)
- Paul Mankiewich, Cisco
- John McHugh, OPASTCO
- Harold Teets, tw telecom
- Marvin Sirbu, Carnegie Mellon University

Statement of Work

The working group focused on:

- tower siting,
- federal, state and local rights of way,
- infrastructure build out,
- permit processing and schedules,
- new technologies to facilitate deployment,
- education of state and local officials.

Top Ideas for Consideration

1. Permits for Federal Rights of Way
2. Municipal Best Practices for Permitting and Coordination
3. Tower Siting
4. Technology Opportunities
5. Building Ingress

Permits for Federal Rights of Way and Antenna Siting

Problem

- Federal agency reviews are lengthy and requirements are inconsistent.
- Manual, paper-based processes dominate reviews.

Proposed Ideas

- Promote standard document format for permitting processes.
- Identify one agency to co-ordinate a unified process for permit approval, with standardized time frames for review and approval.
  - NTIA Federal Rights of Way Working Group report published in April, 2004 which can be used as a starting point.

Next Steps

- FCC-sponsored initiatives to develop inter-agency standardized requirements for antenna siting and rights of way applications.
- Establish a common form and process for acquiring approval from all involved federal agencies, within a specific, reasonable, time frame (e.g., 60 days).
- Ideally, both above steps could be contained within an Executive Order.

Municipal Best Practices for Permitting and Coordination

Problem

- Inconsistent state and local municipality permitting processes and policies result in uncertainty, discouraging and/or delaying investment.
- Inconsistencies between municipalities in determining rates for pole attachments

Proposed Idea

- FCC-sponsored identification of best practices which
  - Reduce delays and uncertainty in permitting processes
  - Promote notification of street opening to utilities (e.g. Reverse one-call)
  - Suggest adoption of a uniform rate for all broadband providers attaching to a pole

Next Steps

- FCC-sponsored municipality and service provider surveys to identify cities that are best in class in broadband deployment.
- Identify and publish best practices for permit requirements and processing.
- Encourage collaboration to identify tools to assist municipalities in identification and implementation of best practices for permitting
- Develop communication (web or e-mail) process for municipalities to advise providers of planned utility projects.
  - Establish a recommended notification window (*e.g.* 90 days for planned utility projects)

Tower Siting

Problem

- Applications are frequently determined to be incomplete multiple times in the process.
- Environmental Assessment processing timeframes are inconsistent.
- State and local zoning requirements for new builds are unnecessarily being applied to co-locations on existing towers.

Proposed Ideas

- Permitting authority should cooperatively work with applicant to correct incomplete application within a short time frame (e.g., 5 days).
- Establish consistent time frames for Environmental Assessment (EA) reviews which should be completed concurrently with other permit processing.

Next Steps

- Encourage permitting authority to mitigate delays due to insufficient application by working cooperatively with the applicant to correct deficiencies.
- FCC-sponsored workshops to educate permitting authorities about the benefits of expediting approvals, and the negative impacts of ordinances that arbitrarily limit tower height.
- Investigate processes employed in other advanced broadband countries such as exemption from extensive processes when within certain parameters; much shorter approval timeframes.
- The FCC should support short “shot clock” and “co-location by right.”

Technology Opportunities

Problem

- Limiting the variety of new technologies used to deploy broadband and optimize networks causes delay in construction and increases broadband deployment costs.

Proposed Idea

- FCC-sponsored education that offers government and the public an appreciation of the benefits of using these efficient new technologies to optimize networks and deliver content.

Next Steps

- Develop a “road show” to highlight how taking advantage of new technologies can accelerate the deployment of broadband to the consumer.
- Develop a website, with collaboration tool capability, available to all municipalities and governments, to drive understanding and acceptance of new technologies for broadband deployment.

Building Ingress

Problem

- Building management policies that are inconsistent and restrictive cause broadband deployment delays and increased costs.

Proposed Idea

- FCC-sponsored education and communication with private land and building owners.
  - Focus on impact to broadband deployment and investment growth and benefits to private owners.
  - Identify best practices for egress.

Next Steps

- Brochure developed by the FCC highlighting the benefits of broadband deployment in private buildings.
- Identify best practices and create a common tool to educate building owners.

End

Technology Advisory Council

IPv6 Transition Working Group

December 20, 2011

Actions Taken

- Recommended ongoing government/industry Working Group to oversee U.S. IPv6 transition
- Recommended IPv6 issues be coordinated among relevant government agencies
  - Outreach to NTIA and OSTP
- Organizing workshop with NTIA on IPv6
  - Status, Policy, Benchmarking
- Developed draft benchmarking profile to monitor IPv6 progress
- Recommended establishment of CEA IPv6 working group

Government/Industry Work Group

- Ongoing work group should be established to oversee multiyear transition to IPv6
- NTIA/FCC and key industry sectors should be represented
  - Initial discussions are underway with NTIA
- Our Working Group provided the initial benchmarking document to monitor IPv6 progress
  - U.S. progress should be compared with other global entities

IPv6 Governmental Coordination

- Multiple federal agencies have distinct roles in IPv6 evolution
- TAC IPv6 work group recommended that government agencies coordinate IPv6 activities
  - Unified voice to work with industry
  - Sharing of information and experiences
- Acting on recommendation, FCC/NTIA meeting to discuss respective roles and responsibilities
  - Jointly sponsored IPv6 workshop outgrowth of these discussions
  - As an outcome to ensure that those roles are clear and communicated effectively to industry
- Expanding discussions to include OSTP, others

Workshop on IPv6

- Working with NTIA to hold workshop on IPv6 in 1Q 2012
- Dialogue on key IPv6 issues
  - Current experience/status (IPv6 Day experiences)
  - Policy issues for IPv6 Evolution
  - Benchmarking strategies
- Government and Industry participants
- Communication on outcome of the workshop including key governmental roles, responsibilities and establish key next steps deliverables

Benchmarking

- Established an initial benchmark document for monitoring IPv6 progress inclusive of all key sectors
  - Includes application sectors, consumer devices, network services, content providers
    - Each area should be responsible for monitoring their own progress
  - In most cases sources of data are proposed
  - Shared with multiple agencies/organizations
- Necessary to gain consensus on benchmarking approach
  - Will require discussion with governmental groups and industry
  - Evolve benchmarking approach as appropriate
- Need to compare U.S. efforts against global progress
  - Better understand other regions IPv6 policy
  - Ensure U.S. remains competitive

IPv6 Sector Groups

- Working group believes more detailed information required from key sectors
  - Status, timelines, issues, strategies
- Recommends that key sectors establish IPv6 sector groups to coordinate activities
- Consumer Electronics Association has established their working group
  - Experience gained in this activity can be applied to other sectors

Summary

- IPv6 transition is critical to future health of U.S. Internet
  - IPv6 will efficiently support the future "Internet of things"
  - However, the transition brings challenges and a range of issues
- We strongly believe and recommend that this challenge be raised to a national level of awareness and monitored during the transition phase
- FCC will provide regular assessments on status and issues regarding IPv6 evolution to the TAC body
  - Possibly bi-yearly updates to ensure progress

2012 Potential Topics

- Continue IPv6 work
- Continuing PSTN transition work
  - Interconnection Issues
  - Robustness/Power Outage Concerns
  - Transitioning Non-Voice Technologies
  - Numbering Systems
- Receiver standards
- ENUM registry implementation (including directory service issues)
- Measuring performance of the Internet
- Opening up 3550-3650 MHz band for licensed in-building device use
- Access to new network products
- eRate definition of support equipment
- Network needs of the cloud

Spectrum Efficiency Metrics

White Paper

Sharing Work Group*

Technological Advisory Council

Draft – 15 December 2011

*Sharing Work Group contributors to this White Paper were Peter Bloom, John Chapin, Richard Currier (current editor), Brian Daly, Dick Green, Dale Hatfield (former editor), Julie Knapp, John Leibovitz, Geoffrey Mendenhall, Dan Reed, Dennis Roberson, Jesse Russell, and Paul Steinberg.

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Executive Summary

The FCC established a non-partisan Technological Advisory Council (TAC) of private sector, public sector, and academic specialists to help address some of the most strategic policy and technical issues that the Commission faces.

The TAC is comprised of a number of work groups, including one designated as the Sharing Work Group. This TAC has the responsibility to formulate recommendations to promote near term private investment and job creation. To accomplish this objective, the Sharing Work Group has focused on techniques such as spectrum sharing, facilities sharing, acceleration of small cell technology to improve localized coverage for cell phones using smaller, lower power transmission technology, and elimination of current friction points in the application of improved communication technology.

All communication systems that send or receive signals wirelessly, including telephone, television, radio, satellite, radio telescopes, and consumer electronics, consume a scarce resource known as radio spectrum. This spectrum comprises a range of radio frequencies that are allocated for licensed or unlicensed use to operators and/or users of each wireless communication system. Spectrum must be allocated and managed to prevent intentional or unintentional interference between wireless communication systems and devices as well as to guarantee acceptable levels of service for the users of all wireless communication systems.

This white paper is the result of extensive work by the Sharing Work Group to help improve the methods by which this scarce radio spectrum is evaluated, allocated, and utilized. Even though this is a highly technical subject, the Sharing Work Group believes that any interested reader should be able to understand and respond to the critical issues that are described.

The radio spectrum is a finite resource on which demands for access continue to grow. The ability to better share the radio spectrum is an important enabler of increasing access to it by the ever growing universe of radio-based services. The current cell phone systems provide an excellent example of how the widespread sharing of spectrum among cell phone uses provides this continually expanding availability and breadth of application services. In the future, the further expansion of these kinds of services to ever wider portions of the spectrum and both heterogeneous and homogeneous application classes is highly desirable.

To accomplish this goal, it is important to develop a uniform set of metrics that can be used to measure and describe the efficiency of how various segments of the radio spectrum are being utilized. Without a coherent and unbiased measurement system, there is no way to judge whether particular frequencies in the spectrum can be further optimized, better shared, or in some cases allocated for a different use to broaden their value to a wider range, or in some cases more valuable range (e.g. public safety), of users.

Just as counting the number of cars on a highway is not the only measure of a road’s value, efficiency is not the only consideration when it comes to re-evaluating the use of spectrum. Overall cost, quality of service, reliability, security and operational considerations are issues that must also be carefully weighed. The primary objective of this paper is to characterize spectrum efficiency metrics that can establish a foundation for creating jobs to "design, manufacture, deploy and maintain more spectrally efficient technologies".

A key report, published in October of 2008 by the National Telecommunications and Information Administration's Commerce Spectrum Management Advisory Committee (CSMAC) highlights how difficult it is to establish a uniform metric for spectrum efficiency. No single set of metrics captures the full range of issues because the underlying technologies are so varied and the services provided are so broad. Consequently, a taxonomy was developed of different classes of systems (e.g. broadcast, personal communications, radar, satellite, passive listeners such as radio telescopes, short-range systems, etc.) that share enough common characteristics that individual efficiency metrics are useful.

The Sharing Work Group has expanded on the original taxonomy, creating a refined taxonomy that is described in detail in this paper. The updated taxonomy is split into six classes. There are two classes of satellite systems (broadcast and point-to-point) and four classes of terrestrial systems (broadcast, personal communications, point-to-point, and hybrid). Potential measures of efficiency are described in detail for each class. Radar is also considered as a separate class since it occupies "a significant portion of the most desirable regions of the radio spectrum resource."

One of the revolutions in wireless technology has been the development of devices and systems using technologies like Bluetooth and Wi-Fi that communicate over a short range using frequencies that are currently part of radio spectrum that is not licensed by the FCC. The Sharing Work Group is continuing to assess potential efficiency metrics for these unlicensed technologies but has not included any conclusions on this topic in the paper.

To better characterize metrics for satellite systems, the paper distinguishes between communication services and non-communication services. For each of these, the report explains in detail how efficiency can be measured. For satellites, factors such as antenna size, field of view, orbital arc, and responsiveness are also described as part of the overall evaluation of relevant metrics.

There is also complexity in assessing the different efficiency characteristics of the four classes of terrestrial systems. In addition to engineering factors, there are a number of critical policy and public-good related considerations that must be considered. These include unfettered and appropriately prioritized access for public safety and provision for service to rural areas, even though investment return for service providers is often lower in these less densely populated communities.

The Sharing Work Group took an integrated systems approach to this entire evaluation because every component of a radio based communication system involved with either the transmission and/or reception of a signal has to be considered as part of efficiency. The good news is that there is already precedent for sharing these systems to increase efficiency. For instance, sharing can be enhanced by mitigating interference through the introduction of filters and separating users by different technical characteristics (e.g. transmission techniques).

The efficiency metrics described in this paper can form the basis for an even more robust use of existing technologies which can drive capital investment, job creation, and a wealth of advanced services to support the needs and desires of the people of this great country.

Establishing metrics for measuring the efficiency of spectrum utilization provides a foundation for optimizing the use of this finite resource through cooperative actions between the FCC and all other stakeholders. Once spectrum efficiency metrics have been established to provide a technical basis for evaluation and comparison, in the opinion of the Sharing Work Group, a combination of market-based incentives and appropriate regulatory mechanisms is required to stimulate progress towards increasing spectrum utilization efficiency, allocation efficiency, and sharing based on the spectrum efficiency metrics and other relevant criteria. Fortunately, there are established precedents for work between government and the private sector to improve the allocation and utilization of other scarce resources. Markets for tradable wetland credits, pollution credits, and CAFE standards for improving automotive fuel consumption are some examples that the Sharing Work Group recommends as models for the FCC to consider as it continues to make progress towards more efficient use of this vital national resource. Additional work is required on the metrics proposed in this document before they can be used to support market incentives or regulatory mechanisms. In the coming year, the Sharing Work Group intends to further develop the metrics and prepare case studies of how they are to be applied.

I. Introduction

The radio spectrum is a national and international resource of increasing economic and social value. It is critical to the safety of life and property and to national defense and homeland security. Wireless systems of all types depend on this congested resource. The efficiency of spectrum usage must improve at an accelerating rate if the Nation is to accommodate rapidly increasing demand for wireless systems and applications and to stimulate related job growth. Metrics are necessary to support the national effort to improve spectrum efficiency. Unfortunately, as discussed herein, the various services that rely on spectrum differ so fundamentally that there is no single universal measure of spectrum efficiency.

While it does not appear possible to develop a single measure of spectrum efficiency, metrics have been developed that allow efficiency comparisons to be made among similar spectrum uses. Such metrics can be a useful tool. For example, they can help assess historical gains in efficiency, evaluate the gains that might be achieved with new or improved technologies, and identify opportunities for evolving to more efficient systems or for implementing replacement technologies.

It is important to distinguish the efficiency of spectrum allocations from the efficiency of wireless systems. Although the two concepts are closely related, they differ because spectrum allocations are increasingly shared by multiple systems. Spectrum managers are primarily concerned with the efficiency of spectrum allocations. Spectrum allocation efficiency can be improved through increased efficiency of the systems using that allocation, increased sharing with other systems, or some combination of those approaches.

It should be emphasized at the outset that spectrum efficiency is not the only factor to be considered in spectrum management decisions. Other factors including the overall cost, the quality of service (QoS), the availability of equipment, compatibility with existing equipment and techniques, the reliability of the system, the security afforded by the system, and operational factors all affect the choice of the best system in a given circumstance.

With that *caveat*, the purpose of the Working Group's effort and of this White Paper is to identify, analyze, and describe spectrum efficiency metrics for a taxonomy of different services with the hope that jobs will be created immediately to design, manufacture, deploy, and maintain more spectrally efficient technologies that are "fit for purpose" and, over the longer term, to create expanded opportunities for the growth of the wireless industry and, hence, for the Nation's economy more generally.

The balance of this report is divided into six sections. Section II summarizes prior work in the area of spectrum efficiency metrics while Section III identifies and describes the six classes of systems upon which the Working Group concentrated its initial effort and also identifies additional classes that may be analyzed in its future efforts. Section IV then addresses spectrum efficiency metrics for satellite systems while Section V addresses terrestrial systems. Section VI offers further thoughts on spectrum efficiency metrics and in particular the importance of viewing these metrics from a systems perspective, while Section VII offers the summary and conclusions associated with the Working Group's efforts on spectrum efficiency metrics to date.

Appendix A provides a table (still largely unpopulated at this point) illustrating the use of spectrum efficiency metrics. Appendix B provides a table illustrating representative examples of spectrum sharing experience in US FCC history. Appendix C provides an initial set of case studies of instances where receiver performance played a significant role in spectrum allocation decisions and often the related inefficiencies in the current use of the spectrum.

II. Summary of Prior Work

The Working Group began its work on Spectrum Efficiency Metrics by identifying and reviewing prior work in the area. An important item in that regard was a report entitled "Definitions of Efficiency in Spectrum Use" which was prepared by Working Group 1 of the Commerce Spectrum Management Advisory Committee (CSMAC) and dated October 1, 2008.[A] As touched upon above, the CSMAC report recognized that it was impossible "to establish a uniform metric for spectrum use efficiency that encompasses the wide range of services and uses for which spectrum is needed."[1] Therefore it first developed a taxonomy of spectrum use (i.e., classes of systems that had enough characteristics in common to indeed be comparable) and, second, identified and discussed possible spectrum efficiency measures for each such class. The classes addressed in the CSMAC report included the following:

Broadcast Systems
Personal Communications Systems
Point-to-Point Systems
Radar Systems
Satellite Systems
Passive Listeners (e.g., radio astronomy)
Short Range Systems[2]

The CSMAC report on definitions of spectrum efficiency drew upon an earlier report/recommendation by the International Telecommunications Union entitled "Recommendation ITU-R SM.1046-2, Definition of Spectrum Use and Efficiency of a Radio System."[B,3] In developing this report, the Working Group also took note of a presentation entitled "Frequency Use Status Investigation and Spectrum Utilization Metric" by Sang Yun Lee at the International Symposium on Advanced Radio Technology (ISART) in 2008[C], NTIA Report 94-311 by R.J. Matheson entitled "A Survey of Relative Spectrum Efficiency of Mobile Voice Communication Systems" and dated July 1994[D], and a presentation entitled "What is Spectral Efficiency" by Dag Åkerberg of the DECT Forum in 2005[E].

Importantly for the study conducted by the Working Group, ITU-R SM.1046-2 "Definition of Spectrum Use and Efficiency of a Radio System"[B] provides a definition of Spectrum Efficiency. ITU-R SM.1046-2 defines the Spectrum Utilization Efficiency, SUE, (or Spectrum Efficiency as a shortened term) of a radiocommunication system by the complex parameter:

[1] CSMAC, Working Group 1 "Definitions of Efficiency In Spectrum Use", October 1, 2008, p. 2.
[2] The CSMAC report also included a category labeled "Cognitive Systems" that addressed "cross application efficiencies" or inter-service efficiencies that could be produced by what it termed "cognitive adaptive spectrum use."
[3] Rec. ITU-R SM.1046-2, "Definition of spectrum use and efficiency of a radio system," 2006.

$$SUE=\{M,U\}^4 \qquad (1)$$

where:

M: is the useful effect obtained with the system in question; and
U: is the spectrum utilization factor for that system.

The spectrum utilization factor U – how much spectrum is consumed – is defined as the product:

$$U = B \cdot S \cdot T \qquad (2)$$

where:

B: is the frequency bandwidth denied to other potential users,
S: is the geometric space (usually geographic area) denied to other potential users; and
T: is the time denied to other potential users.[5]

The Working Group relied on this definition of Spectrum Utilization Efficiency for several portions of its work. In the Working Group's interpretation of this definition, the parameter B may differ from the frequency bandwidth allocated to the system. B is larger than the allocated bandwidth when some aspect of the system's design or implementation – for example the filters used in its receivers – restricts usage of adjacent allocations. B will not be smaller than the allocated bandwidth if the allocation is exclusive; however B may be smaller if the allocation is shared between the system in question and other users. Another goal of efficient spectrum utilization should be as nearly 100% time utilization of each spectral bandwidth slice as possible. Spectrum not fully time utilized is "laying fallow". The time utilization of spectrum depends on the type of service and the ability of services to share the same spectrum if the duty cycle is less than 100%. The spectrum efficiency metric should include the time utilization and/or the ability of a service to share the spectrum during the time the spectrum is not fully utilized.

III. Proposed Taxonomy and Focus

Having reviewed the prior work described above, the Working Group studied two broad classes of systems – Satellite Systems and Terrestrial Systems – and, within those two broad categories of systems, focused its initial analytical attention on six classes of systems:

Satellite Broadcast Systems
Point-to-Point Satellite Systems

Terrestrial Broadcast Systems

[4] ITU-R SM.1046-2 suggests one possible specific relationship to be SUE = M/U.
[5] Spectrum utilization increases with the fraction of time that the spectrum is available. The specific value for T depends upon the system(s) being considered. ITU-R SM.1046-2 suggests that time be ignored (i.e. T = 1.0) for continuously active systems. In other cases, "time" might be set to the fraction of time the system is active.

Terrestrial Personal Communication Systems
Terrestrial Point-to-Point Systems
Terrestrial Hybrid Systems – Public Safety / Utility

In the two sections which follow, each of these six classes of systems is discussed, and related spectrum efficiency metrics are proposed. The challenges associated with the development and usage of the associated metric is discussed, and sample calculations for each efficiency metric are supplied.

In addition to the four classes of terrestrial systems listed above, the Working Group also considered radar systems. In doing so, it concluded (as the CSMAC report on definitions of spectrum efficiency had done before) that commonly applied efficiency measures (such as bps/Hz) are not appropriate for radars since the spectrum efficiency of a radar system cannot be directly compared to the spectrum efficiency of a typical communications system. The Working Group also recognized that radar systems themselves vary widely in terms of the services they provide and the technologies that they employ and that, subcategories of radar systems may be needed to properly compare them. While the Working Group took note of recent technological advances that might allow significant spectral efficiency improvements (e.g., the adoption of linear solid state Laterally Diffused Metal Oxide Silicon – LDMOS transmitter systems and advances in pulse shaping technology), it was unable to identify or evaluate suitable spectrum efficiency metrics for radar systems at this time. The Working Group also took note of the fact that the annual ISART conference held in July, 2011, was devoted almost entirely to spectrum management aspects of radar systems, and the presentations might provide a resource for developing an appropriate spectrum efficiency metric for radar systems. This is especially important as radar systems utilize a significant portion of the most desirable regions of the radio spectrum resource. In any event, the Working Group intends to continue to work on the radar issue by, among other things, incorporating results from the ISART conference and through engagement with academia.

Finally, the Working Group touched upon but did not address in any depth spectrum efficiency metrics for “passive” (mostly scientific) uses of the resource and short range systems that typically operate on an unlicensed or “licensed by rule” basis. The CSMAC referred to the former as Passive Listeners, and it includes the receive-only systems that are used to detect natural electromagnetic omissions in certain bands that have been allocated for the purpose. Perhaps the most well-known example is radio astronomy where users study radio emissions from stellar objects and distant galaxies, for example, to gain a better understanding of the universe and how it evolved. The CSMAC report noted that, while the spectrum efficiency of a passive listening system may not be a definable metric, the amount of spectrum used (the frequency range or bandwidth, the guard band size, the geographic area and the time duration of the associated measurements) can be determined. It went on to explain that, by using more directive receive antennas (at added cost of course), spectrum efficiency could be enhanced by reducing the separation distance between the passive receiving site and potentially interfering transmitters. While the Working Group has so far been unable to pursue spectrum metrics for passive uses more extensively, it did reach out to radio astronomers in the National Radio

Astronomy Observatory ("NRAO")[6] in order to understand current issues associated with radio astronomy spectrum and more fully explore potential alternatives for analyzing such systems. The NRAO informed the Working Group that:

1. Appropriate dynamic spectrum sharing could work along with appropriate temporal and spatial exclusion zones. Some exclusion zones may need to be in the range of 100 miles.
2. The 1400 – 1421 MHz "H1" radio astronomy band is used only in a couple dozen areas worldwide. This band needs to be protected only around the limited number of locations where it is used.
3. The NRAO is quite concerned about consumer vehicle radar detectors in the 76 – 81 GHz band. Because these radar detectors can destroy a radio telescope sensor if they cross the telescope bore sight, it would be helpful to have on/off switches in vehicles that could be operated in conjunction with warning signs near the telescope.
4. Bringing mobile devices into a radio astronomy site needs to be avoided because close proximity of mobile devices operating in any band will degrade radio telescope performance.

With regard to the latter, short range systems that typically operate on an unlicensed or licensed by rule basis, the Working Group noted the increased importance of unlicensed systems such as WiFi (the IEEE 802.11 family of standards) and Bluetooth (IEEE 802.15.1). The Working Group also recognized that, while systems used in consumer applications like WiFi, Bluetooth, baby monitors and cordless telephones (and even microwave ovens) garner much of the attention in terms of unlicensed, short-range spectrum uses, the same spectrum is used in a wide variety of other commercially important applications, including "off-loading" cellular data traffic from licensed systems to WiFi. While it is clear and demonstrable that WiFi systems, for example, have increased their spectrum efficiency rather dramatically over the past decade, it is far less clear how other unlicensed systems have evolved in that regard. Thus, as pointed out in the CSMAC report, while the spectrum efficiency of say a campus-wide WiFi system can be assessed using the metric of bits/sec/Hz/km^2, it is far less clear how to assess the spectrum efficiency of other specialized systems for which there is little information available, nor how to assess the efficiency of the usage of an unlicensed band in total. It is also a challenge to assess the overall spectrum efficiency of a system that uses both conventional cellular technology and WiFi to provide commercial wireless data services. As in the case of passive systems, it is the intention of the Working Group to study and/or support the study of these issues in more detail by, for example, further engaging the academic research community.

IV. Spectrum Efficiency Metrics for Satellite Systems

Satellite systems encompass a significant diversity of service types[7] such that it is difficult and not necessarily meaningful to establish a single spectrum efficiency metric that would apply to

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[6] The National Radio Astronomy Observatory, founded in 1956, is a facility of the National Science Foundation that provides state-of-the-art radio telescope facilities for use by the international scientific community. More information is available at http://www.nrao.edu/.

[7] Satellite system *service types* include non-communication systems such as navigation systems ("Global Positioning System"), weather sensors, and imaging systems (used for Google Earth and maps), and a variety of communication

all service types. For example, communication satellite systems include both broadcast television systems ("DirecTV" and "Dish" in the United States), which are intended to distribute the same content to a large number of viewers, and mobile telephone systems ("Iridium", "Globalstar", "Terrestar", "Inmarsat", etc.), which operate essentially as a satellite-based cellular telephone network. Just as it has been recognized that different spectrum efficiency metrics are applicable to terrestrial broadcast television systems and personal communication systems, it is appropriate that different spectrum efficiency metrics should be applicable to satellite systems providing these different service types. For satellite systems, therefore, appropriate spectrum efficiency metrics need to be defined based on *service type*.

Most fundamentally, satellite system service types can be divided between those that provide *communication services*, which are intended to convey a communication, typically digital data, from a sender to a receiver, and *non-communication services*, which include a variety of non-communication applications such as navigation services, weather monitoring, earth observation research, and imaging. Within communication service types, it is useful to make the following distinctions:

1. *Broadcast systems* vs. *point-to-point systems*, in which broadcast systems are intended to distribute identical content from one origination point to many reception points, while point-to-point systems are intended to establish many individual communication links between two points (senders and receivers).
2. *Fixed service* vs. *mobile service*, in which a fixed service uses a stationary high gain antenna that requires precise pointing to the satellite, while a mobile service allows user mobility through the use of an omni-directional antenna that does not require pointing.

An additional distinction that will be useful for metric definition is *geostationary* vs. *non-geostationary* satellite system, which specifies whether or not the satellite operates in an orbit that is geostationary. While this distinction is more of a system architecture characteristic as opposed to a service type, it does affect the amount of spectrum re-use that can be achieved between different satellite systems, so it therefore influences how spectrum efficiency is determined.

Within each service type, an appropriate spectrum efficiency metric will be proposed. As a consequence of the system design tradeoffs in satellite systems, it is sometimes possible to improve a spectrum efficiency metric by making a change within the system design that degrades a value point for the end user. For example, spectrum efficiency in terms of bits-per-second-per Hz of spectrum can be increased by increasing the size (antenna aperture diameter) of the user antenna, which enables higher order modulation to be employed. Larger antenna sizes, however, are generally undesirable, especially in consumer applications. It is therefore useful to identify *additional efficiency considerations* that will need to be evaluated along with the core spectrum efficiency metric to provide an overall evaluation of the spectrum efficiency so that the stand alone spectrum efficiency metric does not drive an undesirable satellite system design.

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systems including television broadcast systems ("DirecTV" and "Dish") and systems providing point-to-point two-way communication links.

1 Communication Satellite Systems

Communication satellite systems are those intended to convey a communication, typically digital data, from a sender to a receiver.

1.1 Broadcast Systems

A satellite broadcast system is intended to distribute identical content from one origination point to many reception points within the *common program area*. The satellite broadcast system may divide its total service area (coverage area) into multiple common program areas, each of which receive a common set of content. Within the United States, typical common program areas can be the time zones or local television channel broadcast areas ("local into local").

The proposed spectrum efficiency metric is **Information bits per second per Hz of spectrum consumed within each common program area ("bits / (second – Hz)")**.

The spectrum efficiency metric needs to be assessed within each common program area because the number and size (square miles) of the common program areas are determined by the intended service objective and are therefore not an appropriate driver of the spectrum efficiency. Whether a broadcast service is intended to deliver a single program, such as the Super Bowl, to the entire United States, or to deliver localized content to local areas such as individual US states is determined by the service objective and is not an appropriate measure of spectrum efficiency. Rather, broadcast system spectrum efficiency is determined by how efficiently the spectrum within each common program area is utilized.[8]

A broadcast satellite system can deliver the same content to an arbitrarily large number of users within the common program area. Adding users does not consume any of the system capacity, as with terrestrial broadcast over-the-air television, so the number of users does not need to be considered when defining the spectrum efficiency metric.

1.2 Point-to-point Systems

Point-to-point satellite systems are intended to establish many individual communication links between two points (senders and receivers) to allow information, typically digital data, to flow between those two points. The satellite system establishes this capability across the satellite's service area (coverage area). Because adding users does consume system capacity, unlike broadcast satellite systems, consideration does need to be given to the system capacity per area, since the number of potential users is proportional to the size of the service area. Capacity per service area can be increased via frequency re-use, similar to terrestrial cellular systems, so the spectrum efficiency metric should give credit to higher levels of frequency re-use.[8]~~6~~

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The proposed spectrum efficiency metric is **Information bits per second per Hz of spectrum consumed per square kilometer of service area ("bits / (second – Hz – sq. km.)").**

[8] The spectrum efficiency will increase with frequency re-use both geographically and via dual polarization, and the proposed spectrum efficiency metric will give credit for both types of frequency re-use.

2 Additional Efficiency Considerations

These additional efficiency considerations need to be evaluated in addition to the spectrum efficiency metric so that a comprehensive determination of the satellite system efficiency is properly made.

2.1 Antenna Size

Satellite system user value is enhanced when the size[9] of the antenna is reduced. There is a correlation, however, between user antenna size and the spectrum efficiency metric. Within certain limits, increasing the antenna size, and hence decreasing user value, will allow greater spectrum efficiency through the use of higher order modulations (i.e., moving from QPSK to 8PSK to 16QAM etc.). In terms of overall system optimization and user value, it is not always desirable to use the largest possible antenna sizes to achieve the greatest spectrum efficiency. Antenna size must therefore be included as an additional efficiency consideration when evaluating the spectrum efficiency metric of satellite systems.

2.2 Consumed Field of View for Geostationary Satellite Systems

A given geostationary orbital position ("orbital slot") has a potential service field of view[10] that is the approximate one-third of the earth's surface that is visible from that orbital position. A satellite placed at that orbital position will be designed to use a particular portion of the frequency spectrum to provide service to a defined service area, which will be a portion (subset) of the field of view. No other satellite placed at that same orbital position can use the same portion of the frequency spectrum to provide service to the same service area. If a second satellite is placed at approximately that same orbital position to re-use the same frequency spectrum to serve a different service area within the same field of view[11], there will be a service exclusion zone surrounding the defined service area of the first satellite that cannot be served by the second satellite due to inter-system RF interference.[12] "Consumed field of view," therefore, is the geographic region for which a satellite denies access to another co-frequency satellite operating at the same geostationary orbital location ("slot"). The size of this service exclusion zone relative to the service area and the service field of view must therefore be included as an additional efficiency consideration when evaluating the spectrum efficiency metric of satellite systems.

2.3 Consumed Orbital Arc for Geostationary Satellite Systems

When a geostationary satellite at a particular orbital position ("orbital slot") is providing service to a given service area using a portion of the frequency spectrum, there is an orbital arc exclusion range surrounding that orbital position from which no other geostationary satellite can provide service to the same service area using the same frequency spectrum due to inter-system RF interference. "Consumed orbital arc," therefore, is that portion of the geostationary orbital arc

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[9] Antenna size refers to physical aperture area for a parabolic reflector or phased array antenna, physical size for a microwave feed horn antenna, and dimensions for a dipole or other omni-directional antenna.

[10] The "service field of view" is that portion of the earth's surface that is visible from, and hence serviceable from, the geostationary orbital slot.

[11] As an example, two geostationary satellites co-located at 90° west longitude could each use the same frequency spectrum so that one satellite serves the United States and the other satellite serves Brazil.

[12] As an example, if a satellite has the United States as its service area, there will be a portion of southern Canada and a portion of northern Mexico that cannot be served by a co-located satellite operating in the same frequency spectrum.

for which a satellite denies access to another co-frequency satellite seeking to serve the same geographic region. The size of this orbital arc exclusion range must therefore be included as an additional efficiency consideration when evaluating the spectrum efficiency metric of satellite systems. The size of the orbital arc exclusion range will be substantially greater for mobile service satellite systems, in which omni-directional antennas are employed by the user terminals, relative to fixed service satellite systems, in which narrow beamwidth antennas are employed by the user terminals.

2.4 Consumed Geographic Regions for Non-geostationary Satellite Systems

A non-geostationary satellite system will have satellites in one or more orbital planes that may or may not have rotational periods that synchronize with the earth's rotation. Based on the orbital planes and rotational periods, some percentage of the earth's surface will be blocked from employing co-frequency satellite communications to other non-geostationary satellite systems and geostationary satellite systems. The size of the geographic region that is consumed by a non-geostationary satellite system and unavailable for other co-frequency satellite systems must therefore be included as an additional efficiency consideration when evaluating the spectrum efficiency metric of non-geostationary satellite systems.

2.5 Responsiveness for Two-way Point-to-point Satellite Systems

In two-way point-to-point satellite systems, user value is enhanced when response time is decreased. There is a correlation, however, between response time and the spectrum efficiency metric. Within certain limits, decreasing the response time, and hence increasing user value, will reduce spectrum efficiency by reserving a greater percentage of the spectrum for the signaling associated with dynamic spectrum resource allocation.[13] In terms of overall system optimization and user value, it is not always desirable to cause excessively long response times to achieve the greatest spectrum efficiency. Response time must therefore be included as an additional efficiency consideration when evaluating the spectrum efficiency metric of satellite systems.

3 Non-communication Satellite Systems

Non-communication satellite systems include a variety of non-communication applications such as navigation services, weather monitoring, earth observation, and imaging. While it would be desirable to develop a set of spectrum efficiency metrics for non-communication satellite systems similar to what has been done for communication satellite systems, in fact, non-communication satellite systems are so unique that it is the Working Group's current opinion that it is not practical to identify a spectrum efficiency metric that would be meaningfully extensible beyond any individual non-communication service or system. Across service types, it is not practical to identify a common spectrum efficiency metric that would apply, for example, to navigation satellites, weather monitoring satellites, earth observation satellites, and imaging satellites, because these applications are so fundamentally different. Within each non-communication service type, the service definition of each system will have great impact on the service capabilities and corresponding spectrum usage. For example, in a navigation satellite system, the spectrum usage will be driven by the location precision required, specification of the cold-start acquisition time of the receivers, and the incorporation of ancillary information such as

[13] In satellite systems, response time is also determined by the latency resulting from propagation delay of the radio signal as it traverses the distance between the satellite and the earth terminals. This latency is influenced by whether the satellite is in a high, medium, or low altitude earth orbit.

absolute time and/or frequency references. Because of the vast range of specifications that is possible for each navigation service definition, a spectrum efficiency metric for a "generic" navigation satellite system would also not be meaningful or useful. As a specific example, the service definitions for the existing and planned navigation satellite systems (GPS, Galileo, GLONASS, and BeiDou) are so different that any metric including "total spectrum consumed" is not meaningful in a comparative sense because of the differing service capabilities. The Working Group recommends, therefore, that in the case of non-communication satellite systems, the designers and implementers of these systems should be encouraged to develop an appropriate spectrum efficiency metric for their particular system and use it as a guideline in the system design and license application processes with the objective of using spectrum efficiently. The spectrum efficiency metrics developed for each particular system can also be used to provide benchmarking against appropriate commercial standards and to allow for tracking of improvements over time. These spectrum efficiency metrics should consider including both transmitter and receiver characteristics. The Working Group is also very interested in any university research that might provide further illumination in this area.

4 Concluding Thoughts on Metrics for Satellite Systems

In this subsection, spectrum efficiency metrics for both broadcast and point-to-point satellite *communications* systems have been proposed and additional efficiency considerations have been identified and discussed. *Non-communications* systems and applications like navigation services (e.g., global positioning systems), meteorological (e.g., weather satellites), earth observation (e.g. ocean and earth temperature and humidity observation), and remote sensing (e.g., imaging systems) have been discussed, and given their unique nature, an individualistic approach to achieving spectrum efficiency has been proposed. Finally several areas have been identified where additional academic research would be valuable to further refine these metrics and associated considerations.

V. Spectrum Efficiency Metrics for Terrestrial Systems

To an even greater degree than the satellite systems case discussed in Section IV, terrestrial systems encompass an extremely large variety of services including non-communications services such as radar systems. For the reasons explained earlier, the Working Group was unable to identify or evaluate suitable spectrum efficiency metrics for radar systems for this version of the White Paper. The Working Group was, however, able to address spectrum efficient metrics for the following classes of systems: *Broadcast Systems, Personal Communications Systems, Point-to-Point Systems, and Hybrid Terrestrial Systems – Public Safety / Utility*. Each of these four classes of systems is discussed in the subsections that follow.

The working group recognized that the Commerce Spectrum Management Advisory Committee (CSMAC) had reported definitive findings for spectrum efficiency for the systems discussed here. Therefore, the material below closely follows that work and some sections of the text have been taken directly from the CSMAC report.

1 Terrestrial Communications Systems

1.1 Terrestrial Broadcast Systems

Terrestrial Broadcast systems are similar to satellite broadcast systems in that they distribute identical content from one origination point to many reception points within the common geographic area. A broadcast system can deliver the same content to an arbitrarily large number of users within the same geographic area. Adding users does not consume any of the system capacity. As the number of users increases, the spectrum efficiency improves when compared to point-to-point systems where each additional user consumes additional spectrum. Similarly, for broadcast systems there is a tradeoff between intended coverage areas and independent usage. For example, satellite systems may achieve large coverage areas but if the signal is intended as a local signal then much of the coverage may be effectively wasted. Conversely, if large coverage is desired then land based broadcast systems may need to operate using multiple frequencies with the same information content to avoid interference issues. Broadcast systems provide multiple data sets that are individually selectable by the many recipients. This may allow a definition of efficiency based on the number of independent data sets that are available per MHz.

For broadcast systems, efficiency can be defined in terms of the served audience per amount of utilized spectrum. For a national audience, a single frequency assignment carried everywhere may well be the most efficient, thus favoring systems such as satellite. For a localized but dense audience, localized reuse of spectrum may provide the most audience coverage per bandwidth, thus favoring traditional land based broadcast. For a sparse audience, some combination of broadcast with unicast with a more cellular arrangement might actually prove the most efficient, though perhaps not the most cost-effective from an overall system point of view.

Referring to formula 1 above from ITU-R SM.1046-2[B], the useful effect (M) of a television broadcast is determined by the number of users (population) able to receive the broadcast. The useful effect of a television broadcasting system would vary with the population density in different parts of the geographical area in question and the number of radio (audio) or television programs that can be received.

ITU-R SM.1046-2 provides details on how to assess the Spectral Efficiency for television broadcasting systems. The spectral efficiency of audio broadcasting systems can be similarly derived. For our purpose here, we will use the component parameters to establish a proposal for an efficiency metric.

The table contained in Appendix A outlines several measures for spectrum efficiency of broadcast systems.[14] They include: 1) bits/sec/Hertz 2) bits/sec/Hertz*km^2 3) bits/sec/Hertz*users 4) bits/sec/Hertz*km^2 * duty cycle. An additional column related to spectrum use duty cycle is also listed. The proposed spectrum efficiency metric could also include the area in square kilometers served by the same information bits per second per Hz of spectrum consumed within each common geographical area ("bits / (second – Hz)" times the average number of users simultaneously served).

Therefore, the proposed spectrum efficiency metric per user, is: **Information bits per second per Hz of spectrum consumed within each common geographic area ("bits / second / Hz)"**

[14] Later versions of the table will include spectrum efficiency metrics proposed for other systems.

times the average number of users simultaneously served. Consideration does not need to be given to the system capacity per area, since the number of actual users is proportional to the size of the service area for typical user densities. Capacity per service area can be increased via frequency re-use, similar to terrestrial cellular systems, so the spectrum efficiency metric should consider higher levels of frequency re-use.

1.2 Personal Communications Systems

Terrestrial personal communications systems are similar to satellite point-to-point systems discussed above. They establish many individual communication links between two points (senders and receivers) to allow information, typically digital data, to flow between those two points. Adding users does consume additional system capacity, unlike broadcast systems. For this class of service we can define spectral efficiency as: Bits per second per Hertz per unit area in a fully loaded system for a given quality of service. A problem with even this practical definition is that it still must assume what an acceptable bit error rate might be (quality of service) and, also, what an acceptable coverage level might be (since there is a relationship between coverage and levels of interference or frequency reuse).

Another difficulty with this definition is that bits per second per Hz would suggest that higher degrees of modulation would always yield more efficiency. However, frequency reuse is also impacted in multi-cell systems by interference, and in practical fact, this is the ultimate limitation on the capacity and / or performance of the system and therefore its spectral efficiency. Higher order modulation might require lower channel reuse thus yielding lower efficiency in the multi cell environment. It is possible to use smaller cell sizes to increase the metric of bps/Hz/area and perhaps appear to get higher efficiency. This approach neglects the higher cost associated with an increased numbers of cells.

Despite the above, we can define efficiency practically for this class of system using equation (1) by fixing a target cell size and computing for that cell size a net bps/Hz/area value over a sufficiently large area to encompass full frequency reuse of all assigned channels.

Following Lee’s formulation:

$$\text{Spectrum Efficiency (personal com)} = \frac{\text{info rate (bps/Hz)}}{\text{Occupied Area}}$$

The proposed metric is: **Information bits per second per Hz of spectrum consumed per square Km of service area (“bits / (second – Hz – sq. Km.)”).** Once again, it is critical to account for an occupied area that includes a full system frequency re-use pattern in order to make fair comparisons among different systems.

An alternate metric that is of the same form (i.e. bits / (second – Hz – <area>)) but more commonly used in evaluating cellular system spectrum efficiency is: **Information bits per**

second per Hz of spectrum consumed per cell ("bits / (second – Hz – cell)"). This "per cell" metric is used by industry organizations such as the IEEE (Institute of Electrical and Electronics Engineers) and the 3GPP (3rd Generation Partnership Project).

1.3 Point-to-Point Terrestrial Systems

These systems have efficiency considerations that are similar to the previous category. Improved modulation schemes can achieve better use of an assigned band. Thus a simple bits/hertz/area metric can be a useful indicator. In addition, in point to point systems, higher directionality has the benefit of mitigating interference among nearby installations, thereby allowing spectrum reuse in the same geographic area.

Using equation (1) from ITU-R SM.1046-2, the useful effect M of a point to point (p-p) system can be estimated. However, in p-p systems, it is also important to consider the total distance over which the information is transmitted. For digital systems, the useful effect can be measured by the transmission rate, multiplied by the total distance over which the information is transmitted. The spectrum utilization factor U for a p-p system can be determined using equation (2).

Following Lee's formulation:

$$\text{Spectrum Efficiency (p-p)} = \frac{\text{info rate (bps/Hz) x Transmitted Distance}}{\text{Occupied Area}}$$

Occupied Area = $S = \frac{1}{2} R^2 \theta_{HP}$

R : sector radius (Km) and θ_{HP} : halfpower beamwidth (rad)

The proposed metric is: **(Information bits per second per Hz of spectrum consumed) x (transmitted distance) per square Km of service area)**

More details on the above parameters as well as examples of calculation of Spectral Efficiency for point to point systems can be found in ITU-R SM.1046-2. Results are sometimes expressed using the metric of number of voice channels/Hz/area for analog p-p systems and bps/Hz/area for digital p-p systems.

1.4 Hybrid Terrestrial Systems – Public Safety / Utility

Hybrid terrestrial systems utilize a combination of broadcast and point-to-point communications modes, typically over wide operating areas. Several other system-level considerations should be taken into account when measuring spectral efficiency for these types of systems. As mentioned above, communications systems must often meet basic user needs in a number of quality of service (QoS) measures, including latency/access time, coverage/reliability, information error rates, and peak-loading requirements. Maintaining this service level or even improving it in some of these areas may have a negative impact on spectral efficiency metrics, but may be required for particular system applications. For example, mission-critical public safety systems have very rigorous QoS, coverage/reliability, and peak-loading requirements, which must be met for the system to be considered useful. Certain communications modes may have much higher QoS requirements than others (e.g., mission-critical public safety voice communications vs. consumer-grade mobile broadband internet access). Good system design practices will take these factors into account. System-level cost considerations (e.g., of backhaul, user equipment, etc.) are also important in many applications.

In general, spectrum is a limited resource with differing value based on geographic location, user density, and criticality (e.g. priority) of the communication itself. Spectrum in densely populated urban areas is generally much more valuable than spectrum in sparsely populated rural areas. As such, it is more important to invest more resources into maximizing spectral efficiency in densely populated, high-use areas where the need for efficient spectrum use is the greatest. Maximizing spectral efficiency in sparsely populated areas generally has a lower return on investment. High spectral efficiency communications systems may be applied to low user density areas, as long as they meet all user QoS requirements, as well as any system cost constraints. Note that some communications systems (e.g., public safety, utility systems) must cover large geographic areas even though few active users may typically exist per square kilometer. Such systems should not be unduly penalized in any spectral resource optimization attempt.

Since the class of public safety / utility communications systems have many distinct requirements in the above areas, an independent *public safety / utility* (i.e., public good) system class is proposed to measure their spectral efficiency levels. Public good systems are typically more performance driven than revenue and throughput driven in nature (as compared to commercial cellular systems, that attempt to deliver the largest number of bits per unit area[15] in order to serve typically large numbers of users). Public good systems may need to cover large areas with very high reliability,[16] and may have very high peak-loading requirements (requiring significant over-resourcing of communications capability).[17] Spectrum utilization should be as nearly 100% time utilization of each spectral bandwidth slice as possible. Spectrum not fully time utilized is "laying fallow". Public safety / utility communications systems typically operate with a lower duty cycly than some other services such as broadcast which operate at 100% duty cycle. Future system designs should improve the spectrum use duty cycle of public safety / utility communications systems while maintaining the high QoS / availability required.

In many respects, the public safety / utility class of communications has similarities to broadcast and satellite communications (covering multiple users or groups over large geographic areas for most communications). Similar to terrestrial broadcasting systems, as the number of users increases, the spectrum efficiency improves when compared to point-to-point systems where each additional user consumes additional spectrum. Thus, a spectral efficiency metric similar to those discussed in ITU-R SM.1046-2 is proposed: **Information bits per second per Hz of**

[15] The metric proposed above for personal communications systems ("Information bits per second per Hz of allocated (licensed) spectrum per square Km of service area") is equivalent to a bits per unit area measure.

[16] For example, mission-critical public safety systems generally have at least 95% coverage reliability requirements with less than 3% bit error rates over those areas.

[17] For example, public safety systems generally require at least a 15:1 peak to average communications capacity (i.e., having 15 times the user capacity available for emergency situations compared to average communications needs) with less than 1% call/access blocking probability.

spectrum consumed over the geographic area served "(info bits / second / Hz) * km^2" times the average number of users simultaneously served including duty cycle. Note that this metric directly takes into account the number of users served in each possible communications mode (whether it be broadcast messaging, talk-group messaging, or individual communications). Most public safety / utility systems utilize a mix of these different communications modes, with a bias towards group communications. The same mix of communications modes should be used whenever comparing different communications systems for spectral efficiency. Also note that if a particular system solution does not meet the user QoS requirements discussed above, it is not generally useful and should be removed from consideration. Therefore, the QoS requirements form a hard constraint on system viability, regardless of the underlying communication system's spectral efficiency levels.

VI. Further Thoughts Relating to Spectrum Efficiency Metrics

1 Factors Impacting the Amount of Spectrum Consumed by a System

This section amplifies the brief discussion given in Section II of the Spectrum Utilization Factor proposed by ITU Recommendation ITU-R SM.1046-2.

While from the outset the Working Group recognized that spectrum efficiency necessarily requires consideration of both the transmitting and receiving portions of a wireless system as well as the interaction between the two, most of the initial analysis was on transmitters. Evaluation metrics, to be truly useful, must consider the entire end-to-end system since both transmitters and receivers use spectrum resources. Communications systems can deny the use of part of the spectrum to another system that would cause interference to, or experience from, the first system. Basically, a system consumes spectrum resources when it denies other systems the efficient and effective use of those resources.

The importance of the receiving portion of a wireless system can perhaps be best seen through an example. Imagine an ideal world in which a transmitter only occupies a single 10 MHz channel (i.e., there is no "spillover" into adjacent channels due to the use of "brickwall filters") and further assume that the transmitter is achieving a very high level of spectrum efficiency (as measured in bits/second/Hz) in that channel. Now imagine that the distant receiver associated with the transmitter is of poor design and is unable to reject signals that occupy the adjacent 10 MHz channels on either side of the channel actually occupied by the transmitter (i.e., the desired channel). In this example, the relevant measure of the spectrum actually being consumed is not 10 MHz, rather it is 30 MHz. Viewed in this manner, the actual spectrum efficiency is much less than that calculated considering the transmitter characteristics alone.

More generally, there are several items that should be considered when evaluating spectrum utilization efficiency[18] and which may be worthy of further study, perhaps in an academic research environment. As noted above, the amount of spectrum that is consumed by a radio system such that it is not available for other radio systems (i.e., the spectrum utilization factor[19]) is a function of both the transmitter and receiver performance. When determining the spectrum

[18] "Spectrum Utilization Efficiency" is defined in section 2 of Annex 1 of ITU Recommendation ITU-R SM.1046-2

[19] "Spectrum Utilization Factor" is defined in section 2 of Annex 1 of ITU Recommendation ITU-R SM.1046-2.

utilization factor, therefore, a complete radio system view including both the transmitters and receivers must be undertaken.

A given radio system including both transmitters and receivers may only utilize portions of the spectrum as opposed to completely consuming the spectrum. Three examples of instances where spectrum can be partially consumed are guard bands, spread spectrum modulation, and complex, higher order modulation schemes. In the case of guard bands, the practical limits of filter rolloff in the receivers will likely require some mitigated spectrum use in the immediately adjacent guard bands, but it may be possible to partially load the guard bands with "quieter" less interfering competing radio systems, such as, for example, a beacon system with a low duty cycle. In the case of spread spectrum modulation, by the nature of spreading carriers across a substantially greater bandwidth than theoretically necessary to support the information content, the occupied spectrum becomes partially loaded but can support, up to certain limits, additional spread spectrum carriers and/or standard, un-spread carriers from competing radio systems. In the case of radio systems using higher order modulation with high complexity, these systems require especially high signal-to-noise ratios that may make them particularly sensitive to emissions from competing radio systems in nearby geographic areas and/or adjacent spectrum. As a consequence, when determining the spectrum utilization of a given system, consideration must be given to any instance in which spectrum is partially consumed.

An interesting situation arises when a new technology is developed that permits deploying an additional system in some of the spectrum consumed by an existing system, without harmful interference to the existing system. When the additional system is deployed the amount of spectrum consumed by the existing system decreases, according to the definition used by the Working Group, without any change to the existing system. This is precisely equivalent to deploying a system using a 5 MHz wide carrier in a 10 MHz wide allocation, then later reducing the allocation to 5 MHz wide without changing the system. The efficiency metric improves without technical change to the deployed system. There is no paradox as long as it is kept in mind that spectrum consumption is a property of a particular system as deployed in the field, rather than a property of the technology used in that system.

In certain types and architectures of radio systems, additional spectrum-related resources beyond the standard resources of frequency bandwidth, geographic area, and time may be consumed. Two such examples are orbital arc range consumed by a geostationary satellite system (previously discussed in Section II.2.3) and spectrum available for aircraft at various altitudes consumed by a terrestrial radio system. When the spectrum utilization of a particular type of radio system is evaluated, consideration must also be given to additional spectrum-related resources that are of value to radio systems and may also be consumed.

As discussed above, there are several figures of merit associated with a radio system that can be enhanced in a manner that may cause a reduction in spectrum efficiency. These figures of merit include cost, physical size of the radio unit, physical size of the antenna, global portability, choice of frequency options, and QoS performance parameters such as bit error rate and response latency in multiple access systems. It may be the case in certain radio systems that some combination of cost reduction, size reduction, and performance improvement can be achieved along with a necessary reduction in spectrum efficiency. The impact of improving spectrum efficiency on these related figures of merit needs to be considered in making a comprehensive evaluation of the radio system.

2 Allocation Efficiency and Spectrum Sharing

As described in the introduction, the efficiency of a spectrum allocation is derived from the set of systems currently sharing that allocation. The efficiency of the allocation increases with improvements in the efficiency of one or more of those systems, or with the addition of new systems sharing the allocation.

This intuitive statement of allocation efficiency hides significant complexity. When different services measured with different metrics share an allocation, or when two systems with different geographic or spectrum extent overlap, it is difficult to mathematically combine their measured efficiencies usefully to produce a single allocation efficiency value. Nevertheless, it is valuable to pursue metrics for allocation efficiency. Spectrum managers can use such metrics to assess and drive towards higher efficiency, while leaving it up to spectrum users the best strategy to meet those goals.

The Working Group did not develop methods for quantitatively measuring allocation efficiency in its 2011 work. This is a work item for 2012. However, the Working Group took the first steps towards that work by collecting specific examples of spectrum sharing previously authorized by the FCC. These examples, summarized in table form in Appendix B, will be the basis for the study and analysis needed to make forward progress in this area.

The sharing mechanisms identified in historical examples fall into the following categories:

- Separation in frequency: One user operating near to another selects a noninterfering frequency for transmission, and incorporates sufficient filtering to reject transmissions by the other.
- Separation in time: One user operating near to another on an interfering frequency avoids transmitting at the same time as the other.
- Separation in space – static: Spectrum is re-assigned to different users operating with enough geographic separation to avoid interference among users (e.g., re-assigning the same broadcast television channel in different cities).
- Separation in space – dynamic: One user, operating on a frequency that would cause interference to another, avoids transmitting when near to the other.
- Separation in the receiver: One user, operating near another on an interfering frequency, selects a waveform that enables the receiver to correctly receive the desired signal despite interference from the undesired signal (spread spectrum (e.g. CDMA and frequency hopping) provides an example of separation in the receiver).
- Operational coexistence approaches: Users employ a range of coordination mechanisms among themselves for preventing interference or resolving it when it arises. Additional proposed coexistence approaches include separation in infrastructure among multiple service providers and a common infrastructure that supports multiple applications and/or multiple service providers.

The table in Appendix B lists examples of all these forms of sharing, with the exception of "separation in space – static" since this sharing mechanism is relatively straightforward, well understood, and has been widely employed since the earliest days of radiocommunications.

3 Case Studies Illustrating the Importance of Receiver Performance

As the Working Group delved into its work and developed a more nuanced view of the factors that impact spectrum utilization and, in particular, the role of receiver performance, it recognized the close relationship between two of the focus topics that the group had been tasked to address: spectrum efficiency and receiver standards / guidelines or performance. As part of its efforts to address the latter – receiver performance – the Working Group developed a draft paper entitled "Case Studies: The Role of Receiver Performance in Promoting Efficient Use of the Spectrum." The paper, included here as Appendix C, summarizes a number of recent examples where receiver performance was a significant issue affecting access to spectrum for new services. It proposes an in-depth study, perhaps by an appropriate academic institution, of the current spectrum allocation table focusing on established guard bands and the characteristics of the receivers associated with existing band edges thus contributing to a better understanding of the possible scope for spectrum reallocation, compaction and sharing.

VII. Summary and Conclusions

- Spectrum use efficiencies must improve dramatically if the Nation is to accommodate rapidly increasing demand for the resource

- Unfortunately there is no single measure of spectrum efficiency that can be applied across all services

- Such metrics have been developed that allow efficiency comparisons across a variety of satellite and terrestrial based systems categories

- These metrics can play an important role in analyzing and comparing similar systems (e.g., as in bps/Hz/sq. km. in the case of personal communications systems)

- In carrying out its work, the Sharing Working Group recognized that, while spectrum efficiency is critically important, it is only one of the factor to be considered in making spectrum management decisions. A variety of system figures of merit including user QoS requirements (e.g., bit error rate, response latency in multiple access systems, and peak-to-average loading ratios), size (e.g., physical size of the radio unit and the antenna), and cost must also be met for a system to be useful.

- Based upon a review of prior work, the Sharing Working Group focused its initial analytical attention on six classes of systems: *Satellite Broadcast Systems, Point-to-Point Satellite Systems, Terrestrial Broadcast Systems, Terrestrial Personal Communication Systems, Terrestrial Point-to-Point Systems and Hybrid Terrestrial Systems – Public Safety / Utility*

- For each of these six classes, the Sharing Working Group developed and discussed a proposed spectrum efficiency metric and sample calculations are supplied for each metric; in doing so, because of the makeup of the Sharing Working Group, it was able to make particularly strong progress in the satellite category

- The Sharing Working Group was unable, at least at this time, to identify and develop a suitable spectrum efficiency metric for radar systems, unlicensed systems, and terrestrial and satellite receive only observation systems, but it intends to continue to work on these systems as well as other system classes not addressed in this report

- The Sharing Working Group identified the importance of separating the notions of Allocation Efficiency and System Efficiency; it intends to consider methods for computing Allocation Efficiency based on the efficiency of the systems sharing a particular allocation in future work.

- Establishing metrics for measuring the efficiency of spectrum utilization provides a foundation for optimizing the use of this finite resource through cooperative actions between the FCC and all other stakeholders. Once spectrum efficiency metrics have been established to provide a technical basis for evaluation and comparison, in the opinion of the Sharing Work Group, a combination of market-based incentives and appropriate regulatory mechanisms is required to stimulate progress towards increasing spectrum utilization efficiency, allocation efficiency, and sharing based on the spectrum efficiency metrics and other relevant criteria. Fortunately, there are established precedents for work between government and the private sector to improve the allocation and utilization of other scarce resources. Markets for tradable wetland credits, pollution credits, and CAFE standards for improving automotive fuel consumption are some examples that the Sharing Work Group recommends as models for the FCC to consider as it continues to make progress towards more efficient use of this vital national resource. Additional work is required on the metrics proposed in this document before they can be used to support market incentives or regulatory mechanisms. In the coming year, the Sharing Work Group intends to further develop the metrics and prepare case studies of how they are to be applied.

General References:

A. Commerce Spectrum Management Advisory Committee (CSMAC), Working Group 1 “Definitions of Efficiency In Spectrum Use”, October 1, 2008 (Available at: http://www.ntia.doc.gov/advisory/spectrum/meeting_files/Spectral_Efficiency_Final.pdf)

B. Rec. ITU-R SM.1046-2, "Definition of spectrum use and efficiency of a radio system," 2006 (Available at: http://www.itu.int/rec/R-REC-SM.1046-2-200605-I/en)

C. Sang Yun Lee, “Frequency Use Status Investigation and Spectrum Utilization Metric” June 2, 2008

D. NTIA Report 94-311, R.J. Matheson “A Survey of Relative Spectrum Efficiency of Mobile Voice Communication Systems”, July 1994

E. Dag Åkerberg, “What is spectral efficiency?” January 2005

Appendix A: Spectrum Efficiency Metrics -- Taxonomy

Frequency Range	Wireless Service Classification	Wireless Service Sub-classification	Metric #1	Metric #2	Metric #3	Met
			bits/sec/Hertz	*bits/sec/Hertz*km* ^{2}	*bits/sec/Hertz/km* ^{2}	*bits/sec* *km /*
Generic Systems						
3.7 - 4.2 GHz 5.925 - 6.425 GHz 11.7 - 12.7 GHz 14.0 - 14.5 GHz 17.7 - 20.2 GHz 27.5 - 30.0 GHz	Satellite System	Broadcast System	Compute for individual system under evaluation.	N/A	N/A	N
3.7 - 4.2 GHz 5.925 - 6.425 GHz 11.7 - 12.7 GHz 14.0 - 14.5 GHz 17.7 - 20.2 GHz 27.5 - 30.0 GHz	Satellite System	Point-to-point System	N/A	Compute for individual system under evaluation.	N/A	N
Various	Terrestrial	Broadcast Systems	N/A	N/A	N/A	N
Various	Terrestrial	Personal Communications Systems	N/A	N/A	Compute for individual system under evaluation. (See Notes.)	N
Various	Terrestrial	Point-to-point	N/A	N/A	N/A	Comp individu under ev
Various	Terrestrial	Hybrid	N/A	N/A	N/A	N
Specific Systems						
174 - 216 MHz	Broadcast Digital Television	High Definition DTV Standard Definition DTV Mobile DTV	19.4 MBPS / 6 MHz = 3.23	19.4 MBPS / 6 MHz * $50km^2$ = 162	N/A	N
470 - 698 MHz	Broadcast Digital Television	High Definition DTV Standard Definition DTV Mobile DTV	19.4 MBPS / 6 MHz = 3.23	19.4 MBPS / 6 MHz * $50km^2$ = 162	N/A	N
200 - 900 MHz (various bands)	Hybrid Terrestrial	Public Safety/Utility P25 Phase 2		4.8kbps/6.25KHz*800km2=614 (large urban area system dispatch) (security/control info incl.) (information spread metric)		
200 - 900 MHz (various bands)	Hybrid Terrestrial	Public Safety/Utility P25 Phase 2		4.8kbps/6.25KHz*100km2=77 (large urban system subdiv. talk group) (security/control info incl.) (information spread metric)		

Frequency Range	Wireless Service Classification	Wireless Service Sub-classification	Metric #1 *bits/sec/Hertz*	Metric #2 *bits/sec/Hertz*km²*	Metric #3 *bits/sec/Hertz/km²*	Met *bits/sec* *km /*
	--				*Specific Systems* --	
700 MHz BB	Hybrid Terrestrial	LTE BB video MBSFN use case		400Kbps/580KHz*100km2=69 (group video over IP streaming broadcast) (384kbps nominal personal video stream) (large urban area system w/1km cells) (streaming security/control info incl.) (macro-cell edge coverage & efficiency issues) (information spread metric)		
700 MHz BB	Hybrid Terrestrial	LTE VOIP MBSFN dispatch use case		11kbps/19.6KHz*800km2=449 (2.45kbps P2 codec/IPv4 packets/100% VAD) (large urban area system dispatch w/1km cells) (roughly ~8x P25 BSs required) (no IP header compression - pkt bundling utilized) (maximum of 60% of chan. BW available) (no MIMO or HARQ, w/E2E security) (51 voice streams/MHz equivalent) (w/addl' VoIP latency) (macro-cell edge coverage & efficiency issues) (VOIP should be small percentage of LTE traffic)		
4.9 GHz	Hybrid Terrestrial	Public Safety/Utility WLAN video use case		54Mbps/20MHz*3km2=8.1 (outdoor video surveillance mesh) (relatively short range <1km) (peak data rate - single hop to data sink)		

NOTES:

Duty Cycle of Spectrum Utilization:

The goal of efficienct spectrum utilization should be as nearly 100% time utilization of each spectral bandwidth slice as possible. Spectrum not fully time utilized is "laying fallow".
The time utilization of spectrum depends on the type of service and the ability of services to share the same spectrum if the duty cycle is less than 100%.
The spectrum efficiency metric should include the time utilization and/or the ability of a service to share the spectrum during the time the spectrum is not fully utilized.

Terrestrial Broadcast Systems:

Broadcast systems are intended to distribute identical content from one origination point to many reception points within the *common geographic area*.
A broadcast system can deliver the same content to an arbitrarily large number of users within the common geographic area.
Adding users does not consume any of the system capacity.
As the number of users increases, the spectrum efficiency improves when compared to point-to-point systems where each additional user consumes additional spectrum.
The proposed spectrum efficiency metric per user is Information bits per second per Hz of allocated (licensed) spectrum within each common geographic area (bits / second / Hz) times the average number of users simultaneously served.
The proposed spectrum efficiency metric could also include the area in square kilometers served by the same Information bits per second per Hz of allocated (licensed) spectrum within each common geographical area.

Terrestrial Point-to-point Systems:

Appendix B: Examples of Spectrum Sharing in the US

Band	Users	Coexistence method: Frequency separation	Coexistence method: Spatial separation	Coexistence method: Time separation	Coexistence method: Signal separation in receiver	Coordination Mechanism	Characteristics of users/services	Notes
54-88 MHz (VHF TV channels 2-6), 174-216 MHz (VHF 7-12), 470-608 MHz (UHF 13-36), 614-698 MHz (UHF 38-51)	TV broadcast; Unlicensed TVWS		Geolocation by unlicensed user			Database of protected users checked by unlicensed before transmission (max 24 hrs)	TV broadcast occurs at fixed locations and changes slowly. Many TV channels locally unused for historical reasons and because of low revenues from TV broadcast service in many locations.	FCC can direct database administrator to never report any available channels to a specific make/model of unlicensed device; this enables rapid resolution of problems if source can be identified.
138-144 MHz, 154-156 MHz	Federal, state, and local public safety agencies in Alaska.	Centrally managed trunked radio system	Centrally managed trunked radio system	Centrally managed trunked radio system		Sharing agreement.	Compatible public safety land mobile needs, the sharing arrangement and P25 technology combine to make efficient use of Federal and local/state channels together.	Called the Alaska Land Mobile Radio (ALMR) system. Pursuant to a sharing arrangement, Federal VHF channels under NTIA jurisdiction and local/state public safety VHF channels under FCC jurisdiction are both use for one combined P25 system serving public sa
174-216 MHz (VHF TV channels 7-12), 470-608 MHz (UHF 13-36), 614-698 MHz (UHF 38-51)	Primary: TV broadcast Secondary: Part 74 stations/devices (Low Power TV, Wireless mics)		Low power TX by secondary			Mic users manually select channel; interference in either direction is easily noticeable, mic user self-corrects.	Locations with high mic usage (sports stadiums, theaters) do not have TV receivers with aerials trying to pick up distant stations.	Mics now operating under a waiver that limits power but gives them two channels free of TVWS devices. Transition to DTV ("cliff effect") may make it harder to determine the source of interference.
225 - 400 MHz	Primary: Federal LMR, other uses including aviation communications Unlicensed devices: primarily at 318 & 390 MHz (e.g. key fobs, garage doors)	Filters on unlicensed devices were improved after interference occurred	Low power TX by unlicensed			Government users avoid specific channels where there is a high density of unlicensed users	Primary user not heavily populated. Unlicensed user has low duty cycle.	Garage door openers had poor filters; when federal LMR systems were activated, openers opened at random time and/or got desensed. Solved by moving garage doors to a small portion of the band, improving filters, retrofitting some older devices and replacin
402-405 MHz	Primary: Meterological Aids (weather balloons) Secondary: Medical Device Radiocommunications Service	Listen-before-talk					Density of balloon use is low. Medical devices are short range.	
401-406 MHz	Same as 402-405 Mhz		Narrow bandwidth, low power TX by secondary				Same as 402-405 MHz	
420-450 MHz	Federal Radiolocation; amateurs; private LMR in Cleveland, Detroit and Buffalo		A few exclusion zones			Social norms in amateur community abhor interference. "Official observers" self-police amateur use. Amateur stations automatically self-identify; each amateur user starts TX with ID.	Amateur community size is limited. Higher power use by amateurs (1500W) is repeaters at fixed locations; mobile use much lower power. Amateur use is low density low duty cycle.	There was a petition to allow higher power RFID at 433 MHz. It was strongly opposed by federal users because of aggregation concerns related to much larger user community and lack of responsiveness if a problem were to arise.
413-457 MHz (specifically the following 4 bands: 413-419, 426-432, 438-444, 451-457 MHz)	[Proposal] Secondary use by medical micro-power networks requiring a high degree of operational reliability	Listen before talk. Secondary chooses among 3 10MHz sub-bands & dynamically switches when current sub-band becomes noisy	Low power TX by secondary		CDMA Spread spectrum used by secondary			Proposal by Alfred Mann/Bioness. Device roughly 1m away from user sends control signals to implant enabling paralyzed person to walk. Implanted receiver has both poor filters and low sensitivity. The primary concern is when person with implants comes very
849-851 Mhz	Co-primary between two providers of air-to-ground data and radiotelephone services				polarization		Two nationwide providers, having custom equipment built for them so can arrange to respect polarization requirements without significant additional cost.	Although coexistence via independent polarization was permitted in the rules, the licensees had the option to bid on non-overlapping blocks; the winning bidders chose this option.

Band	Users	Coexistence method: Frequency separation	Coexistence method: Spatial separation	Coexistence method: Time separation	Coexistence method: Signal separation in receiver	Coordination Mechanism	Characteristics of users/services	Notes
902-928 MHz	Extremely varied, includes: Primary: federal radiolocation Secondary: location and monitoring service Unlicensed: RFIDs, cordless phones, etc.		Low power TX by unlicensed.		Spread spectrum TX by unlicensed.			"Safe harbor" provision deems unlicensed users not to cause interference to secondary users if they meet certain restrictions on signal, antenna height, etc. American Radio Relay League: "The allocation status of this band was not the result of any appare
1549.5-1558.5 MHz	Primary: AMSS [aeronautical mobile-satellite service] safety-related communications Secondary: MSS [mobile phone satellite service], with proposed ground-based ATC [cellular style towers transmitting in MSS band]			Priority access for AMSS - FCC authorization for ATC in this band cites the applicant's use of "a centralized common control facility" capable of directing all mobile users to vacate a channel in < 1 sec, but does not specify the mechanism for determining			Only occasional use by AMSS safety communications	FCC 87.187(q) [paraphrase]: The frequencies in the band 1545-1559 MHz (space-to-earth) and 1646.5-1660.5 MHz (earth-to-space) are authorized for use by the Aeronautical Mobile-Satellite (R) Service. In the frequency bands 1549.5-1558.5 MHz and 1651-1660 M
1710-1755 MHz	DOD communication systems (at 16 protected sites in CONUS); AWS (3G cellular).		AWS licensees must avoid transmission in exclusion zones around specified DOD sites.			AWS licensees must coordinate with DOD in coordination zone around specified DOD sites.		Section 27.1134 of the Commission's rules. AWS licensees must accept any interference received from DOD operations at the specified sites.
1920-1930 MHz	All unlicensed. Dominant use is cordless audio: mostly phones, some baby monitors and mics (DECT standard).	Listen before talk	TX power backoff based on energy level sensed in band				Mostly indoors. Audio needs high quality of service.	LBT/backoff rules were designed to permit continuous connectivity for high audio quality. Original rules were more restrictive; channels were widened and some sensing and backoff rules relaxed before volume deployment took off.
2360-2390 MHz	[Proposal] Primary: Aeronautical telemetry Secondary: Medical body-area networks		Crypto key from access point required before mobile devices transmit; this prevents mobile device TX when too far from an approved location.			Healthcare institutions notify AMT users of MBAN usage, perform frequency coordination if close to an AMT site, agree to halt usage if a problem arises.		Body-area networks = use wireless links to eliminate the annoying wires attached to the sensors on a patient in the hospital.
2400 - 2483.5 MHz	All unlicensed. Also microwave ovens.	WiFi is a de facto incumbent; other services often detect and avoid it.	TX power limit keeps interference range to a few hundred meters	WiFi uses carrier sense multiple access; some other services do not do time separation	Most services employ spread spectrum			
3.1-10.6 GHz	Primary: various unlicensed: UltraWideBand				unlicensed TX has such low power in any channel that primary user signal-to-noise ratio is not meaningfully affected			

Band	Users	Coexistence method: Frequency separation	Coexistence method: Spatial separation	Coexistence method: Time separation	Coexistence method: Signal separation in receiver	Coordination Mechanism	Characteristics of users/services	Notes
3650-3675 MHz	Primary: satellite Secondary: mostly fixed, some limited mobility		150 km exclusion/coordination zone around 64 grandfathered satellite ground station sites			Secondary users must register sites and coordinate. No priority given to first secondary user into the band in a given area.	Primary user active at only a few locations. Secondary user is broadband data (e.g. WiMax) in rural areas.	Coordination is painful and causes lots of complaints; perhaps because this is not a serial negotiation?
3675-3700 MHz	Same as 3650-3675		Same as 3650-3675	Regulatory requirement for systems to use a contention based protocol (e.g. CSMA/CD)				
3700 MHz - above 10 Ghz	Co-primary: Fixed Satellite Services, Point to Point Microwave		Directional antennas, directional propagation at these frequencies			Frequency coordination required		
5250-5350 MHz, 5470-5725 MHz	Primary: Weather and military radars Unlicensed: WiFi and other systems (U-NII)		Listen before talk			Locations of weather radars in 5600-5650 MHz are published. Outdoor unlicensed users located within 35 km of a published site must select a center frequency at least 30 MHz away from the radar's center frequency and must register their transmitter locatio	Radars are highly sensitive to low noise levels. Original approach based on LBT only did not successfully prevent interference, so additional coordination was required in fall 2010.	
5850-5925 MHz	Vehicle-to-vehicle and vehicle-to-roadside communications for intelligent transportation systems. Called the Dedicated Short-Range Communication service (DSRC).					Pre-specified dispute resolution process. All road-side units must be registered. All licensees required to work together to resolve problems. In case of dispute escalating to FCC complaint, systems supporting public safety have priority over others (gove	Mix of safety-critical usage and commercial services in the same band.	FCC prespecified in 90.377 that interference in DSRC will only be deemed to exist if the signal from the later registered unit is within 18 dB of the power level of the earlier registered unit at some point in the coverage footprint of the earlier registe
12.2 - 12.7 GHz	Direct broadcast satellite, terrestrial video broadcast		High attenuation in this band by structures and foliage (isolates DBS receiver if on S side).		DBS antennas directional, pointed S. DBS sats TX from S to N (inherently), terrestrial TX from N to S (by choice).	Terrestrial user has some obligations to provide interference remedies. DBS receiver can be moved to S side of house or tree to gain additional isolation.	Both continuous transmission; both broadcast (one-way).	DishTV and Northpoint. Incumbent and interested new licensee were competitors, so coordination mechanisms and detailed service rules had to be specified by FCC rather than happening voluntarily. Rules vary geographically due to local rainfall conditions;
70-90 GHz	Primary: Federal Secondary: Point to Point microwave					Green/red database oracle.	Highly directional antennas and propagation. Secondary users are fixed.	

Notes on chart:

This chart avoids listing examples where the sharing is accomplished by statically assigning the same frequency in distinct geographic areas

Columns in the spreadsheet

- Band: frequency range or common name of band
- Users: who is sharing the band
- Coexistence method: what mechanisms in the systems' design, operation or deployment prevent interference?
  - Subtypes: separation in frequency, time, space, or in the receiver
    - Frequency: assign different frequencies to nearby users; each receiver rejects the frequency used by others
    - Time: multiple nearby users are active on the same channel; make sure they don't TX at the same time
    - Space: keep one user's TX from reaching another's receiver
    - Receiver: design signals so receiver can separate the desired from the undesired signal
- Coordination mechanisms: what mechanisms external to the systems are used to prevent or respond to interference?
- Characteristics of users/services: what attributes are relevant that enable the selected coexistence methods to work?

Examples of coexistence mechanisms

- Frequency separation: filters
- Spatial separation: low power TX, exclusion zone, directional antennas (TX), indoor/outdoor
- Time separation: priority access
- Signal separation: CDMA, polarization, notching, interference cancellation, directional antennas (RX)
- Coordination mechanisms: negotiation, social norms, database of protected users, green light/red light database, 3rd party managers

Note: the listen-before-talk mechanism supports frequency, time, or spatial separation, based on what parameters are chosen

Appendix C: Case Studies - The Role of Receiver Performance In Promoting Efficient Use of the Spectrum

Spectrum Management has generally focused on transmissions. The radio spectrum is allocated among various radio services as reflected in the Table of Frequency Allocations. Transmitters are subject to requirements to ensure they operate within the spectrum allocated for that service and any out-of-band and spurious emissions that might fall outside the spectrum allocated for that service are carefully controlled to minimize the risk of harmful interference to other services. One might assume that receivers abide by the same principles as the transmitters, in other words, that they only receive transmissions within the spectrum allocated for the service in which they are designed to operate. However, often that is not the case and receiver performance can dramatically affect access to and efficient use of the spectrum.[20]

This Appendix summarizes a number of examples of situations where receiver performance was a significant issue affecting access to the spectrum for new services. It is not intended to parcel responsibility among the various players in each case, but rather to illustrate the nature of the problem in order to develop better ways to prevent or address similar situations in the future. Some of these examples are well-known and long-standing problems that have been dealt with in various ways, such as guard bands or geographic separation, but usually at the expense of some use of the spectrum that would be possible if receiver performance were better.

Many of the potential issues relative to receiver performance and interference between services operating in adjacent spectrum might be avoided through more appropriate placement on the spectrum chart. For example, it is good practice to keep services relying on reception of weak signals in adjacent bands or high-power services in adjacent spectrum. However, services generally cannot be rearranged on the spectrum chart by simply picking them up and moving them to new bands. Often, new services must be placed snuggled into the spectrum space that is available at the time of introduction for the service. This is where the issue of receiver performance that anticipated one type of neighbor and now must deal with a new one comes into play.

Case Studies:

A) The Wireless Communications Service (WCS) was created in 1996 and included 15 MHz spectrum blocks located above and below the Satellite Digital Audio Radio Service (SDARS). The WCS allocation allowed for mobile service, but the technical rules for out-of-band emissions were impractical for mobile devices. After many years of attempting unsuccessfully to deploy a successful business model based on fixed service, the WCS licensees petitioned for rule changes to facilitate mobile service. The performance of the SDARS receivers was one of the critical areas of contention.[21] The receivers had been designed assuming only fixed operations in the

[20] For purposes of this discussion, receiver performance refers to the characteristics that affect the ability to reject harmful interference such as front-end filtering and not to characteristics that are effectively addressed in the marketplace such as voice or picture quality, data throughput, reliability, etc.

[21] *See* Report and Order and Second Report and Order in WT Docket No. 97-293, IB Docket No. 95-91, and GEN Docket No. 90-35, In the Matter of Amendment of Part 27 of the Commission's Rules to Govern the Operation of

adjacent bands and therefore did not anticipate a need for strong filtering of signals in nearby adjacent spectrum. As a result, the prospects of overload interference to legacy SDARS receivers from mobile devices required application of strict technical rules and effectively created 5 MHz guard bands on each side of the SDARS spectrum.

B) The 3650-3700 MHz (50 megahertz) band was re-allocated from Federal government usage (military radars) to non-Federal use in order to meet the requirements of the 1993 budget act. This spectrum was also allocated to the fixed satellite service which had approximately 60 receive sites that could not be relocated to other spectrum. The satellite C-band downlink operates in the upper adjacent spectrum at 3700 – 4200 MHz. An issue that surfaced in the FCC rule making proceeding was that many C-band satellite earth station receivers had front ends extending well into the 3650 – 3700 MHz band. While the FCC deemed the interference risk low due to the directional nature of the satellite service and the anticipated predominant fixed use of this spectrum, the issue risked the possibility of rendering much of this federal transferred spectrum useless.[22]

C) Receiver performance was a major area of contention relative to potential use of the AWS-3 spectrum.[23] The AWS-3 spectrum is upper adjacent to the AWS-1 spectrum. A petition was filed to use the AWS-3 spectrum for time-division duplex operation. However, the AWS-1 receivers were generally designed to operate across the AWS-3 spectrum consistent with international allocations. Incumbent AWS-1 licensees argued that the receivers were not the issue, but rather that TDD operations must not be permitted to operate adjacent to downlink FDD spectrum without a significant guard band. The potential use of the AWS-3 spectrum remains under consideration.

D) The AWS-1 downlink spectrum at 2110 – 1155 MHz is upper adjacent to the broadcast auxiliary service (BAS) band at 2025 – 2110 MHz. AWS-1 licensees were required as the newcomers to coordinate with and correct any harmful interference to the BAS operations.[24] The AWS-1 band had previously been used for the fixed microwave service and so the BAS equipment had not been designed with sharp filters. As a result, AWS-1 operations were found to cause harmful interference to

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Wireless Communications Services in the 2.3 GHz Band and Establishment of Rules and Policies for the Digital Audio Radio Satellite Service in the 2310-2360 MHz Frequency Band at http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-82A1.doc

[22] *See* Memorandum Opinion and Order in ET Docket No. 04-151, WT Docket No. 05-96 and ET Docket 02-380,In the Matter of Wireless Operations in the 3650 – 3700 MHz band, at paras.56-60, http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-07-99A1.doc. See also NTIA Report 94-313Analysis of Electromagnetic Compatibility between Radar Stations and 4 GHz Fixed Satellite Earth Stations discussing solution of satellite receiver overload through use of filtering, http://www.its.bldrdoc.gov/pub/ntia-rpt/94-313/94-313.pdf

[23] *See* Notice of Proposed Rule Making in WT Docket No. 07-195 In the Matter of Service Rules for the 2155 – 2175 MHz band, at pars. 61 – 63, http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-07-164A1.doc

[24] *See* Report and Order in WT Docket no.02-153 In the Matter of Service Rules for Advanced Wireless Services in the 1.7 GHz and 2.1 GHz bands at http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-03-251A1.doc at paras. 127 - 130.

BAS, requiring the AWS-1 licensees to pay to purchase new filters for the BAS equipment.

E) TV Receiver performance was a significant issue for the access of unlicensed devices to the TV White Spaces. The roll-off of the TV filters is the dominant factor limiting the amount of energy that a TV White Space device may emit in the white space and therefore the potential applications for the devices.[25] The issue is pending under reconsideration.

F) The performance of analog TV Receivers was a major factor in the creation of white spaces. Certain combinations of channels known as the UHF taboos were not permitted in any given market due to receiver performance issues. Interestingly, the Commission in the early 1970's contracted with RF Monolithics to develop a TV receiver that would avoid the need for all or most of the taboos.[26] However, though the contracted work was successful, no changes came of this project. DTV receivers were assumed to no longer have this need based on the established policies and the Commission did not apply the protections for the UHF taboos. This would be an excellent candidate for an academic case study.

G) Other issues have occurred through the years relative to TV receivers and services operating in adjacent spectrum: Amateur radio service operations at 50 – 54 MHz interfering with TV receiver on channel 2 at 54 – 60 MHz; mutual interference between TV and FM broadcast at the intersection between channel 6 and the FM broadcast band (largely ameliorated by using only a minimal number of DTV channel allotments on channel 6); interference from services operating in the spectrum at 216 – 220 MHz to TV channel 13 at 210 – 216 MHz; land mobile sharing in 11 major cities operating on TV channels 14 – 20; TV channel 51 operations adjacent to 700 MHz A block mobile wireless licensees -- CTIA has filed a petition asking the Commission not to assign any further TV stations to channel 51[27]; Garage door opener controls operating on Part 15 of the FCC rules on an unlicensed, non-interference basis receiving interference from primary federal land mobile radio systems that could not be remedied easily because the garage door opener controls used super-regenerative receivers with front ends up to 10 MHz wide.[28]

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[25] *See* generally Second Memorandum opinion and Order in ET Docket No. 04-186 and ET Docket No. 02-380 In the Matter of Unlicensed Operation in the TV Broadcast Bands and Additional Spectrum for Unlicensed Devices below 900 MHz and in the 3 GHz Band, http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-174A1.doc

[26] *See* http://ieeexplore.ieee.org/Xplore/login.jsp?url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F5%2F31319%2F01456751.pdf%3Farnumber%3D1456751&authDecision=-203

[27] On March 15, 2011, CTIA - the Wireless Association (CTIA) and the Rural Cellular Association (RCA) submitted a "Petition For Rulemaking and Request for Licensing Freezes" RM-11626, wherein they requested certain actions to limit TV broadcasting on channel 51. The Commission on August 22, 2011 issued a public notice announcing a freeze on the filing and processing of applications for operation on TV channel 51. *See* http://transition.fcc.gov/Daily_Releases/Daily_Business/2011/db0822/DA-11-1428A1.doc

[28] *See* Consumers May Experience Interference to Their Garage Door Openers Near Military Bases, February 15, 2005, http://fjallfoss.fcc.gov/edocs_public/attachmatch/DA-05-424A1.doc

H) Receiver performance relative to adjacent channel and intermodulation characteristics was a major element in the issue of rebanding the 800 MHz spectrum to avoid interference between Nextel and Public Safety operations on interleaved channels.[29]

I) LightSquared's proposed deployment of ancillary terrestrial component (ATC) base stations as part of a hybrid terrestrial – satellite service has raised significant concerns about potential harmful interference to the GPS service operating in the upper adjacent spectrum due to the potential for receiver overload.[30] GPS receiver performance has been raised as one of the elements in this debate. The FCC has not reached any conclusions on the merits nor made any decision on how to proceed in this matter. The issue of overload interference to Inmarsat from L-band ATC operations was addressed by establishing minimal guard bands for certain safety operations and advising that the Commission does not regulate the susceptibility of receivers to interference from transmissions on nearby frequencies. Rather, the Commission relies on the marketplace – manufacturers and service providers – to decide how much susceptibility to interference will be acceptable to consumers. The Commission noted that it generally does not limit one party's ability to use the spectrum based on another party's choice regarding receiver susceptibility.[31]

It is noted that universities (graduate students) might be a low cost means by which the FCC could obtain an in-depth study on the current spectrum allocation table focusing on the review of the established Guard Bands and the examination of the characteristics of the receivers associated with each of the identified "bands of interest" to determine the acceptable specifications for transmitters given the receiver characteristics in neighboring bands. This study would be enormously valuable in understanding the full scope of the opportunity for spectrum re-allocation, compaction and sharing, and in parallel might serve as an excellent learning vehicle for appropriate graduate programs. As with the rest of the Spectrum Efficiency effort, full Working Group and full TAC input on the development of appropriate company and academic R&D incentives for the creation of ever improving receiver offerings is solicited.

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[29] *See* Report and Order, Fifth Report and Order, Fourth Memorandum Opinion and Order and Order in WT Docket No. 02-55, ET Docket No. 00-258, In the Matter of Improving Public Safety Communications in the 800 MHz band, http://www.800ta.org/content/fccguidance/FCC_04-168_08.06.04.pdf

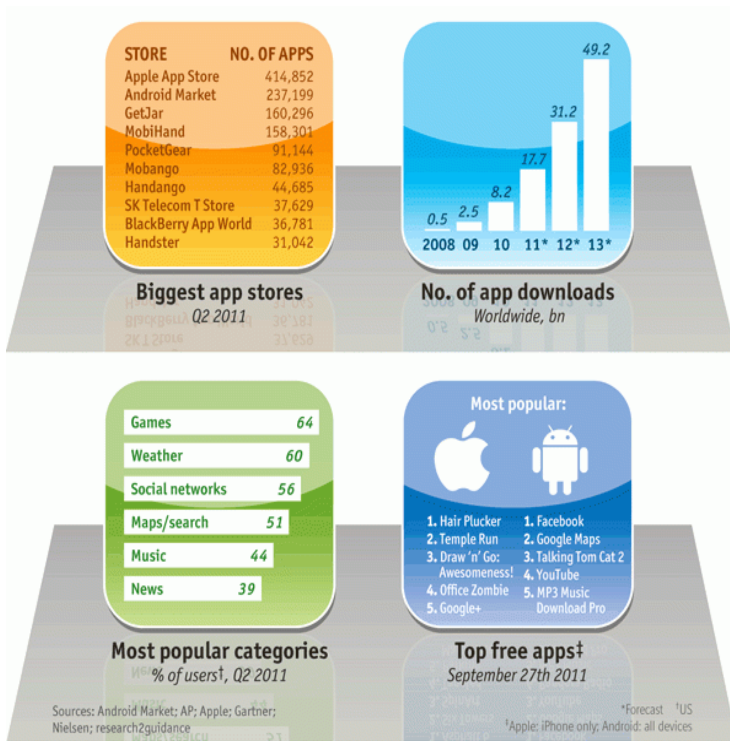
[30] *See* http://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/reports/related_filing.hts?f_key=-216679&f_number=SATMOD2010111800239

[31] *See* Memorandum Opinion and Order and Second Order on Reconsideration in IB Docket No. 01-185, In the Matter of Flexibility for Delivery of Communications by Mobile Satellite Service Providers in the 2 GHz band, the L-band, and the 1.6/2.4 GHz bands, at paras. 51-59, http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-05-30A1.pdf

Technological Advisory Council
Sharing Work Group
White Paper
Application Friction Points
(Draft – 9 December 2011)

I. Introduction

The prevalence of wide-area wireless broadband networks and intelligent devices (smart phones) is making this environment a major force in the creation of new services and applications for businesses and consumers. Market estimates show that global mobile wireless data traffic has increased approximately 3-fold in each of the last 3 years. Wireless communications and mobile devices allow applications that were previously used in a fixed environment (email, social networking, browsing, etc.) to be used almost anywhere, and new applications are being designed and optimized with mobile environments being the first priority target environment.



According to a report from IDC, smart phone sales outstripped PC sales for the first time in Q4 of 2011 and this shift continues with an ever-widening margin. Consistent with this trend, one can see from the data to the right from *The Economist* (8-October-2011) that mobile application uptake is expected to increase exponentially in the coming years.

The environment for true mobile application development is still emerging and it is different than that for computing and Internet based applications based on fixed, wireline connections or even Wireless Local Area Networks (WLANs), aka Wi-. Today's Wireless Wide Area Networks (WWANs) are carrier operated with operators imposing fairly stringent control over devices and (optionally) applications that are allowed to run on their networks. The dominant mobile platforms offer their own applications stores (Apple's App Store and Google's Market), which impose certification requirements to list applications in the store. The hardware and software platforms for mobile application development are far more diverse and rapidly changing than has been true in other domains (e.g., PCs and gaming platforms).

This paper surveys the landscape to identify barriers or impediments (AKA "friction points") to the creation and deployment of mobile application. No fundamentally blocking friction points were identified from our analysis (i.e., there were no obvious 'smoking guns') however several issues are itemized here for consideration in improving the ecosystem around mobile application development with the objective of spurring innovation and economic development.

II. Approach

Our approach for this activity was to call upon our own respective industry knowledge and interview several participants representing different facets of the mobile application environment ecosystem, including carriers, entrepreneurs, academia, and developers. We sought to identify patterns or common themes across these groups and from these patterns, elucidate any specific steps that might be needed to mitigate the friction points. No 'smoking guns' emerged as standout issues or roadblocks; however, several items were identified as possible areas for improvement and/or future optimization for mobile application development.

Contributors to this report include: Brian Daly (AT&T), Julius Knapp (FCC), Daniel Reed (Microsoft), Dennis Roberson (IIT), and Paul Steinberg (Motorola Solutions).

III. Findings

1 Wireless Networks

We received excellent representative presentations from several major wireless carriers on their specific activities around application development communities. Both companies have extensive programs to engender application development and to inform prospective participants about resources and specific procedures. Both companies run events, sponsor application developer conferences, and offer specific hardware specifications and certification services. However, we believe these resources may not be as widely known to, and leveraged by, the application development community as they could and should be.

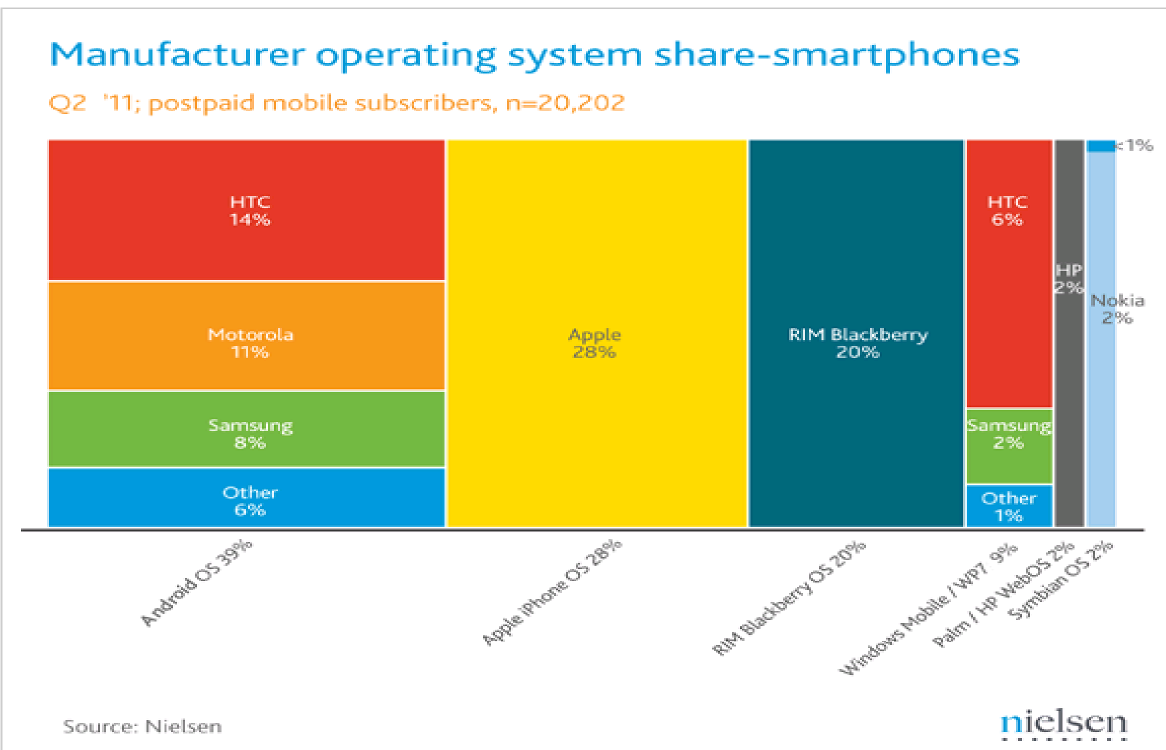
There are several reasons for this, most stemming from the end-to-end (application to infrastructure) certification and management model used by mobile carriers. First, mobile carriers require certification of devices, designed to industry standards, which will operate on their network. Further, each carrier controls all of the authorization/authentication network access aspects for each network user to protect the integrity of the network. While this is quite reasonable in that carriers have a huge investment in their network and must ensure fair/reliable operation for their complete user base (even for emergency services), these steps may add complexity, cost, and delay. By contrast, for example, to build a WiFi or Internet device/applications, so long as one adheres to the industry standards (often implicit in the use of one of several commercially available chipsets and supporting software), then the device can access any network (or other device) with which it can authenticate. Furthermore, in some cases an application may be subjected to not only certification by the wireless carrier(s) but also by the application store(s) in which they may be published. This series of certification (and re-certification) steps is intended to protect the user and network from malware and other security threats but may have the unintended effect for creating hurdles could become stifling from both a time and cost perspective, and by comparison, these layers of certification generally don't exist in the more traditional application ecosystem business models.

Many of the existing mobile network interfaces are well standardized and consistent across the carriers (Messaging, Location, Presence, etc.) with user privacy concerns being an important consideration in making these interfaces available to applications. However, many applications leverage specific device capabilities (e.g., GPS, accelerometers, gyroscopes, altimeters) to add additional functionality. The rapidly increasing numbers of device sensors and variations along with the intense vendor competition to differentiate handsets both suggest that sensor interface standards might lessen the burden of application development across device platforms.

Projecting forward, networks will continue to add capabilities (e.g., interfaces for trusted applications to request and manipulate QoS supported by 4G wireless) that are presently not standardized. In such cases, carriers may even view these capabilities as unique differentiators for their own networks. There are no obvious ways to circumvent or emulate many of these capabilities that are intrinsic to the network itself. Obviously, the development of applications that employ carrier-specific network capabilities is complicated if their access is distinct per carrier and determined at run-time. Like sensor interface standardization, this suggests that there must to be sufficient identification of, and cross-carrier standardization for, any newly emerging, common-denominator network services.

2 Mobile Wireless Platforms

In the smart mobile device category (smart phones, WAN-enabled tablets, etc.), three operating environments have emerged as the prevalent software platforms to date. Google Android, Apple iOS and RIM Blackberry OS account for 87% of the device market share (see *Nielsen* analysis below). Application developers must either focus on a single platform or port and support multiple platforms, and then navigate any requirements imposed by the respective application stores.



Given these challenges, the startup community is developing multiple application development environments for mobile devices. Many of these capitalize on machine independent programming environments such as web-based applications (HTML 5, Scalable Vector Graphics, etc.). There is no clear consensus on the tradeoffs of native vs. web-based runtime agnostic applications relative to performance, but there is general agreement that there are differences and that both native and web-based applications will be required.

It is unlikely that this overall landscape will get simpler. The number of operating system environments is unlikely to decline and in all likelihood will grow or at least change over time. As devices get more capable and complex and as different device applications emerge, the hardware will continue to proliferate as well. While a movement toward platform agnostic environments could bridge some of this, an obvious conclusion is that standardization of interfaces and behaviors for software and hardware platforms would assist mobile application developers. Specification-setting organizations such as the Open Mobile Alliance could help facilitate this direction.

3 Application Building Blocks

Many innovators in the mobile application space, notably academia and entrepreneurs, rely upon a ready supply of accessible and low-cost ingredients from which they can build applications. In particular, the open source community is a key resource for components and tools. These include development and analysis tools, platform building blocks supporting protocols, user interfaces, virtualization, and other common programming elements. Anything that can be done to promote the identification, production and sharing of key highly leveraged resources would be beneficial.

In addition to software tools, some common services or underpinnings are also key application enablers. For example, a mapping service is a common requirement for many mobile applications. Input/output modalities such as speech recognition (speech to text, text to speech, etc.) are also common enablers. For some classes of applications, availability of data sources and schemas are critical bases around which value can be built (e.g., the federal government and many local governments have undertaken efforts to publish data and data formats for critical infrastructure data).

Thus, fostering the creation of common building blocks, tools and common services will facilitate efficient creation of mobile applications. An added benefit is the creation of a common vernacular and knowledge base across the wider development community. A push toward a web-based environment serves two purposes in that it creates a more generic run-time context, and it taps today's most prevalent development mentality in. Finally, it is clear that standardization of operating system environments and platforms, as described in the previous section, also benefits creation of software building blocks.

IV. Conclusions

1. The nature of application development has shifted to emphasize mobile-first.
2. Wireless Networks

A. Relative to traditional fixed networking environments, a higher bar is imposed on mobile applications in order to operate on wireless carrier networks (device certification on the carrier network and application certification by application stores).
B. The [mobile] network itself plays a much larger role in application development than in past, fixed, environments. It is important to standardize common network services (existing and new) across carriers and across network technology epochs (e.g., 3G to 4G).
C. The mobile wireless carriers have advanced and offer diverse application developer platforms, forums and services. These may not be well publicized and are not being tapped as they might be.

3. Mobile Wireless Platforms
    A. Multiple operating system environments create a barrier, especially for native mode applications, requiring multiple ports, increasing complexity and variability for application developers.
    B. Lack of standardization/consistency in device platforms creates porting and support issues for applications. This problem is expected to escalate as the intrinsic capabilities of devices continue to grow as driving greater application complexities.
4. Application Building Blocks
    A. Application developers rely upon common software building blocks, tools, and services from which they can derive their solutions. There are common patterns (open source and/or services) that can be leveraged by many applications. This software is constantly evolving and the emergence of components that are widely adopted is somewhat happenstance.
    B. Increased standardization or normalization for network services, operating system environments, and device platforms can also benefit the efficient production of building blocks

V. Recommendations

This section offers some suggestions on ways that the FCC might engender improvements relative to the conclusions noted in the previous section.

- Sponsor a mobile application developer conference inviting representation across the industry (carriers, entrepreneurs, specific application verticals, academia, device manufacturers, operating system suppliers, etc.). The objective of this forum would be to further inform the ideas put forth in this paper:
    - Publicize existing best practices (e.g., carrier application development community)
    - Vet, extend and clarify the friction points that have been postulated in this document and solicit specific actions and activities from the community.
    - Create specific expert steering groups to develop plans and/or to drive specific initiatives across industry.
- Encourage the formation of specific community of interest groups that can drive standardization (either via explicit standards development or through profiling of

existing standards and best practices). Many of the most effective standards in the past were user-community led.

- Encourage the carriers to establish a common practice and set of network interfaces that application developers can count upon across their collective networks. Also, define common certification methods and practices and ensure that layers of certification (multiple network operators, multiple application stores, etc.) are not unduly imposed.
- Commission a user-community led analysis of key building blocks to identify and prioritize those that are either missing today or likely to be required in the future. Identify funding sources and administer the funding for creation and/or establishment and operation of key capabilities and services.
- As a next-step, conduct a focused 'friction point' analysis of key vertical industries, such as critical infrastructure/utilities, public safety, health care, that could highly leverage wireless infrastructure.

VI. Next Steps

Our efforts to date have mostly focused on the general mobile application environment and not attempted to focus on large specific vertical domains (e.g., health care, critical infrastructure / utilities, public safety, transport and logistics). Many of these vertical areas are transitioning into a mobile environment with increasing dependencies upon WWAN broadband services. In several cases, there is a tradeoff between leveraging existing and emerging commercial networks versus further or creating dedicated purpose built networks (and the associated wireless spectrum). In addition to advancing the recommendations in the preceding section, we propose that the next phase of this work embark upon a deeper analysis of specific vertical segments and the associated friction points that are challenging their use of carrier networks and services. In particular critical infrastructure / utilities[1] and public safety broadband[2] are evolving today and represent an opportunity for significant benefit from reduction in friction that inhibits sharing.

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[1] "The Utility Spectrum Crisis: A Critical Need to Enable Smart Grids", Utilities Telecom Council, January 2009

[2] "The National Broadband Plan Connecting America", Federal Communications Commission (http://www.broadband.gov/plan/)

PSTN TAC Legacy Recommendations

The PSTN is a voice centric network which no longer satisfies all of the interactive communication needs and demands of the citizens of the USA. The transition opens myriad opportunities for new, richer communication capabilities. It is the technical opinion of the Critical Transition working group that market forces will lead to a significant loss of PSTN utilization by 2018 in preparation for which decisions need to begin today. We recommend the following actions:

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1. **Develop a detailed plan for an orderly transition from the current PSTN system of record to a service rich network for achieving key national goals. The plan should include:**
   - A. **A public-private partnership with industry, providers, and relevant organizations and stakeholders.**
   - B. **Coordination mechanisms for the ongoing evolution of the network to rapidly incorporate new technologies and capabilities.**
2. **Establish a task force to conduct a thorough policy and regulatory analysis and review as it relates to the PSTN which results in policies for the new communication environment (Interoperability, Interconnect, E.164, numbering, reliability,…).**
3. **Identify mechanisms and a migration plan for critical services currently provided by the PSTN. Therefore, ensuring that critical services that need to be carried forward are met by well understood solutions. (E911, Disability access,…)**
4. **Commit to ensuring ongoing universal access to evolving communication services to enable all Americans to participate in the nation's economy.**

5. **Investigate the need for the use of incentives to accelerate the transition to new services.**
6. **Create a communications and outreach program to educate the public about the transition.**
   A. **Provide the public with the vision of what we are transitioning to: New services and capabilities can greatly exceed the current services of the PSTN**
   B. **Provide a roadmap and communicate the urgency to take action to avoid the inability to support critical services.**

Note: The term "sunset" does not force providers or consumers not to use PSTN equipment or technologies; however, the sunset removes the policy and expectations from the PSTN. If we do nothing, we will end up with some deep national problems. Accelerating the transition will mitigate these issues proactively. The transition will put the United States on a continued course of technical leadership and innovation in communications.

Appendix A:

Definition of the PSTN

Appendix B

FCC workshop results and details on issues that need to be resolved during the sunset process

Appendix C

Timeline
