Understanding Mobile Broadband for Public Safety

Policy and Technical Update – Afternoon Session

West Virginia Broadband Workshop

August 30, 2011

Homeland Security

OEC/ICTAP

Office of Emergency Communications / Interoperable Communications Technical Assistance Program

OEC/ICTAP-WV-PRES-001b-001

Public Safety Broadband Policy and Planning

MORNING AGENDA (9:00 – 12:00)

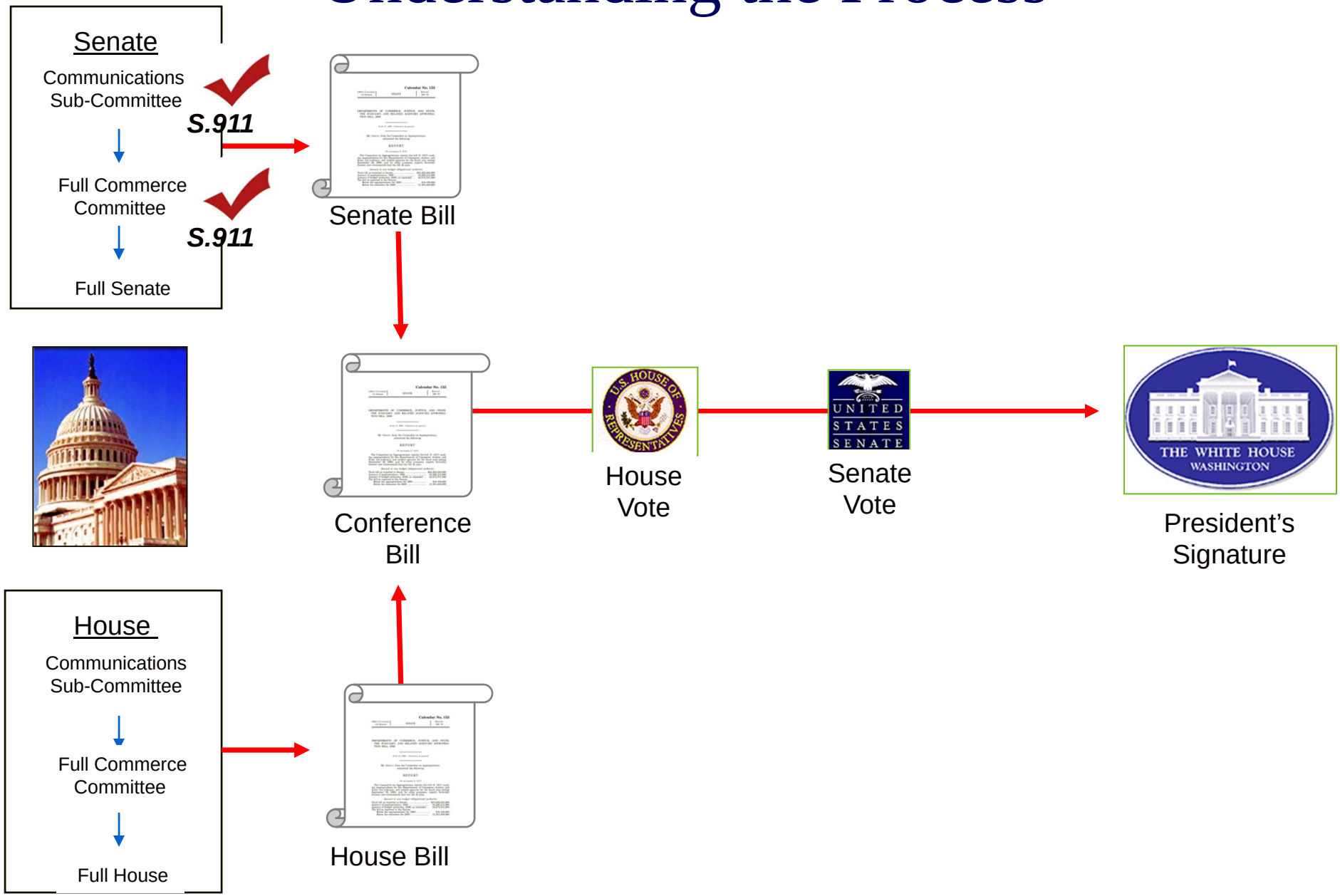
- Overview: The Promise (and Current State) of Broadband (w/ discussion)
- Technology Overview
- *Discussion*
- History and Background of Broadband Policy
- Current Implementation Efforts

AFTERNOON AGENDA (1:00 – 4:00)

- Overview of Current Broadband Legislation
- Stakeholder Information and Engagement
- *Discussion*
- LTE vs. Legacy Voice Comparison *(targeted for technical audience)*

Public Safety Broadband Legislation under Consideration

Understanding the Process



112th Congress Broadband Bills

Chamber / Committee	Sponsor	Bill #	Overview	Status
Senate Homeland	Lieberman (I) / McCain (R)	S.1040	Companion to H.R.607. Reallocates the D Block to the PSST, $11B in funding from spectrum auction distributed through grants, migration of public safety off UHF (10 years)	Referred to Senate Commerce (5/19/11)
Senate Commerce	Rockefeller (D) / Hutchinson (R)	S. 911	Reallocates the D Block to a newly established Public Safety Broadband Corp., $11B in funding from incentive auctions.	Passed Senate Commerce (6/8/11)
Senate	Reid (D)	S. 1323 (Debt Negotiation)	Reallocate D Block, $7 billion in funds. Details to be determined by subsequent legislation (i.e. S 911)	Proposed (7/27/11)
House Homeland	King (R) (45 Co-Sponsors)	H.R.607	Reallocates the D Block to the PSST, $11B in funding from spectrum auction distributed through grants, migration from UHF (10 years)	Referred to House Commerce (2/28/11)
House Commerce	Dingell (D) / Green (D)	H.R.2482	Companion to S.911. Reallocates the D Block to a newly established Public Safety Broadband Corp., $11B in funding from incentive auctions	Referred to House Commerce (7/11/11)
House Commerce	Waxman (D) / Eshoo (D)	Discussion Draft	Similar to S.911, Reallocates the D Block to a newly established Public Safety Broadband Corp, addresses NG 911	Released (7/13/11)
House Commerce	Walden (R)	Discussion Draft	D Block **auction**, Funding for build-out on existing 24 MHz, freezes narrowband voice, authorizes incentive auctions.	Released (7/13/11)
House	Dreier (R)	Debt Ceiling/ Reduction Negotiation	Reallocate D Block, $7 billion in funds. Additional provisions unknown.	Proposed (7/29/11)

Current Approach Overview

S911/ HR2482 / Waxman Draft

- D-Block is Reallocated
- $11B+ for build out, grants, R&D
- Funded from incentive auctions
- Public Safety Broadband Corporation as licensee
- Administered by PSBC with consultation by State designees
- Single Nationwide Network

HR 607 / S.1040

- D-Block is Reallocated
- $11B+ for build out and maintenance
- Funded through auction proceeds & mandated transition off UHF (8 years)
- Public Safety Spectrum Trust (PSST) as licensee
- Funding distributed by 80/20 grants to public safety

Rep. Walden (Draft)

- D-Block is Auctioned
- Existing 700MHz Narrowband is reallocated
- TBD funding for grants after debt reduction
- 50 States are licensees
- Administered by Company selected by FCC based on National Plan
- Network of State Networks Approach

National Governance

	Senate	House	
	S. 911	**Waxman (D) Discussion Draft**	**Walden (R) Discussion Draft**
Approach	Corporate Board of Directors / Public Safety Advisory Committee	Corporate Board of Directors / Program Management Office / Technical and Operations Advisory Body	National Planning Board / FCC Adopts National Plan / FCC RFP for "Administrator" / **Network of State Networks**
Board Membership	▪ **4 Federal Members** *(DOC,DHS,DOJ,OMB)* ▪ **11 Non-Federal Members** *(Including Chair)* All must have either public safety; technical; network or financial expertise • 3 State & local • 3 Public Safety	▪ **4 Federal Members** *(DOC,DHS,DOJ,NIST)* ▪ **7 Non-Federal Public** • 2 Governors • 2 Local/Tribal Executives • 3 Public Safety • **4 Private Sector**	▪ **4 Federal Members** *(FCC,DOC,OEC,NIST)* ▪ **5 Non-Federal Public** • 2 State Public Safety • 1 State/local public safety employees • 2 Other state/local interests (by FCC) • **4 Private Sector** • 2 service providers • 2 equipment manufacturers

Responsibilities of the Governing Body

- Examples of activities of the governing body as included in various bills include:
  - Day to day management of the Network
  - Ensure nationwide standards
  - Create and RFPs for building, operating and maintaining the network
  - Consult with NIST on the certification of devices
  - Manage contracts for deploying the network
  - Negotiate roaming agreements with commercial providers
  - Leverage commercial wireless infrastructure, as well as Federal, State, local infrastructure
  - Promote competition in the equipment market
  - Develop emergency access agreement templates for secondary users
  - Implement an awareness campaign to stimulate adoption
  - Ensure backward compatibility with 2nd and 3rd generation commercial user equipment
  - Promote integration with PSAPs
  - Require deployment phases with substantial rural coverage milestones

Role of State and Local Governance

- **All approaches include consultation with State/locals on issues such as:**
  - Construction of an Evolved Packet Core and Radio Access Network
  - Placement of towers / coverage areas of the network
  - Adequacy of hardening, security, reliability, and resiliency
  - Assignment of priority users
  - Training needs
  - Creating consortium with other States for single RFP for common network requirements

- **All approaches call for a single State Governing Body *(State Public Safety Broadband Office)***
  - Point of consultation
  - Administers grant funds
  - Develop State Broadband Plan (Walden only)

Defining Public Safety Entities

- S 911 Bill defines Public Safety Entities as *Federal, State, and local emergency public safety, law enforcement, emergency response, emergency medical (including hospital emergency facilities), and related personnel, agencies, and authorities.* (Homeland Security Act of 2002)

- Waxman Bill excludes Federal users, but allows the corporation to enter into agreements for shared access to protect the safety of life, health, and property.

- Walden Draft defines as agencies with sole or principal purpose to protect the safety of life, health, or property (limited to State, local and non-governmental)

- FCC Order (FCC 11-113) just released July 21st discussing further guidance on permissible operations for users of the 700 MHz public safety spectrum in response to a Declaratory Ruling filed by Charlotte
  - FCC provided guidance on eligible use and delegated PSHSB to consider uses proposed by government users and issue a ruling as appropriate
  - Agency must be actively providing "public safety services"

Funding

	Senate	House	
	S. 911	**Waxman (D) Discussion Draft**	**Walden (R) Discussion Draft**
Radio Access Network Build Out	**$10.5 Billion**	**$11 Billion**	N/A
EPC Build Out	**$1.25 Billion**		N/A
State & Local Implementation Fund	**$250 Million**	▪ **$250 Million**	**TBD based on Auction proceeds and debt payout**
NIST R&D	**$100 Million per year** (5 years)	**$100 million per year** (5 years)	N/A
National Science Foundation (NSF) Research Grants	**$130 Million per year** (5 years)	▪ N/A	N/A
DARPA Research	**$70 Million per year** (5 years)	▪ N/A	N/A
NHTSA Report on NG 911		▪ **$2 Million**	N/A

S.911: On-Going Funding

- **Corporation is expected to be self sustaining through the following funding mechanisms:**

- **Network User Fee:** Fee from each entity including public safety or secondary user that uses the Network

- **Lease Fee for Network Capacity:** Fee for agreement between the Corporation and secondary user to permit secondary access for non-public safety services and dark fiber for commercial transmissions

- **Lease Fee for Network Equipment/Infrastructure:** Fee for entity that seeks access or use of antennas, towers, etc. constructed or owned by the Corporation.

Next Steps / Remaining Questions

- **There are still a number of pending questions raised by each bill**
  - How do the Waiver Jurisdictions transition onto the Network(s)?
  - Does the proposed structure allow enough local control to address the varied needs of each region?
  - How do secondary responders fit in?
    - Secondary responders are public works, utility crews, transportation, etc.
- **It is unclear when / if the House will take up one of the pending bills for a vote.**
- **As the bills move through the process, they will likely be amended and/or changed**
- **There are some indications that the D-Block and incentive auctions will be considered in the upcoming debt reduction negotiations**

Joint Select Committee On Deficit Reduction

- Charged with finding $1.5 trillion in budget savings
- Spectrum revenue was previously part of August 2nd negotiation and will likely be back on the table.
- Leaders of both positions (reallocation / auction) are represented on the committee.

Senate Members	House Members
Patty Murray (D-WA)	**Fred Upton (R-MI)**
John Kerry (D-MA)	Dave Camp (R-MI)
Max Baucus (D-MT)	Jeb Hensarling (R-TX)
Pat Toomey (R-PA)	James Clyburn (D-SC)
Jon Kyl (R-AZ)	Xavier Becerra (D-CA)
Rob Portman (R-OH)	Chris Van Hollen (D-MD)

"With this latest draft, they have addressed the hard questions of how to fund and manage a national, robust network while reducing the deficit….This bill deserves swift consideration and we should pass it and get it to the President to sign into law before the 10th anniversary of 9/11. It's the least we can do to honor the fallen first responders and the sacrifice they made."

Sen. John Kerry, MA
June 2, 2011

"In 2010, the FCC's national broadband plan found that both our public safety and wireless broadband goals would be better met by auctioning the D-Block…When it comes to broadband, the answer is not simply more federal dollars with federal strings attached…Job creation and deficit reduction should be the priorities for the 112th Congress, not more spending."

Rep. Fred Upton, MI
Feb 10, 2011

Stakeholder Information and Engagement

Outline of Organizations

- **FCC:** Federal Communications Commission
- **PSHSB:** FCC's Public Safety Homeland Security Bureau
- **ERIC:** Emergency Response Interoperability Center
- **PSST:** Public Safety Spectrum Trust Corporation
- **NPSTC:** National Public Safety Telecommunications Council
- **APCO:** Association of Public Safety Communications Officials
- **PSA:** Public Safety Alliance
- **DHS:** Department of Homeland Security
- **PSCR:** Public Safety Communications Research
- **3GPP:** 3rd Generation Partnership Project
- **ATIS:** 3GPP's North American Organizational Partner

FCC

- From 1998 through today, FCC rulemaking has shaped nationwide public safety broadband networks
  - WT Docket Number 96-86, “The Development of Operational, Technical and Spectrum Requirements for Meeting Federal, State and Local Public Safety Communication Requirements Through the Year 2010”
  - WT Docket Number 06-150, “Service Rules for the 698-746, 747-762 and 777-792 MHz Bands”
  - **PS Docket Number 06-229**, “Requests for Waiver of Various Petitioners to Allow the Establishment of 700 MHz Interoperable Public Safety Wireless Broadband Networks”
- The FCC also developed the congressionally mandated National Broadband Plan, which was released in 2010

FCC Information Retrieval

- Use the following URL to retrieve FCC reports, orders & notices
  - http://hraunfoss.fcc.gov/edocs_public/
  - Enter '06-229' in the Docket/RM box
  - The resulting documents are the output from the FCC
- Use the following URL to retrieve inputs to the FCC from various interested parties such as waiver recipients, State and local governments, organizations and companies.
  - http://fjallfoss.fcc.gov/ecfs/comment_search/input?z=43gr7
  - Enter '06-229' in Proceeding Number box
  - There are many documents that will result from this high level search; further refining the search by date or location, etc. is provided and is advisable.
- Use the following to view and listen to FCC meetings
  - http://fcc.gov/events

PSHSB

- **FCC's PSHSB:** Federal Communications Commission Public Safety and Homeland Security Bureau
  - Created in 2005 to coordinate public safety, national security, and disaster management activities within the FCC
  - Develops policies and rules to "promote effective and reliable communications for public safety, national security, and disaster management"
  - Responsibilities include developing policies and rules for public safety broadband
- Provides a good repository of broadband information and links
- Website: http://www.fcc.gov/pshs/broadband.html

ERIC (A Division within PSHSB)

- **ERIC:** Emergency Response Interoperability Center
  - Technical Advisory Committee (TAC) of 19 State and local officials
  - Public Safety Advisory Committee (PSAC) for policy and technical matters includes all levels of government, service providers, equipment providers, etc.
  - PSAC had formed four working groups which reported May 24, 2011
    - Interoperability
    - Network Evolution
    - Applications and User Requirements
    - Security and Authentication
- Key Responsibilities for 700 MHz public safety broadband network
  - Defines technical and operational framework to ensure interoperability and operability
  - Works with PSHSB and FCC on adoption of rules and regulations
  - Implements interoperability regulations
  - Reviews and approves “Interoperability Showings” for waiver recipients
- Website: http://www.fcc.gov/pshs/eric.html

PSST

- **PSST:** Public Safety Spectrum Trust Corporation
  - Directed by representatives from 15 State and local public safety and government organizations
  - Selected by FCC to be the nationwide Public Safety Broadband Licensee (PSBL)
  - Responsible for leasing spectrum to the waiver recipients
  - Created Operator Advisory Committee (OAC) to provide a forum for regular coordination among PSST and waiver recipients
- Website: http://www.psst.org/

NPSTC

- **NPSTC:** National Public Safety Telecommunications Council (NPSTC) Website: http://www.npstc.org/
- Formed a Broadband Task Force (BBTF) that developed a report released in 2009 recommending 700 MHz broadband network requirements
- The Broadband Working Group (BBWG) has developed a functional description of mission-critical voice for broadband
- Currently, the BBWG is focusing on three new topics:
  - Multimedia Emergency Services (MMES) – Non-Voice
  - Priority and Quality of Service
  - State/Local Control of Network

If you have an interest in any or all of these, contact BBWG Chair, Andrew Thiessen at andrew@its.bldrdoc.gov to volunteer

APCO

- APCO: Association of Public Safety Communications Officials - International
- Formed a Broadband Committee to look at public safety broadband applications in use today and make recommendations to meet future mission-critical capabilities
- Website:
  - Broadband Info: http://www.apcointl.org/frequency/broadband_news.php
  - Committee: http://psc.apcointl.org/2011/01/26/apco-international-announces-formation-of-broadband-committee/
  - Broadband Summit and Expo (May 2011): http://broadbandsummit.apcointl.org/

Public Safety Alliance

- The PSA is a partnership with the nation's leading public safety associations
- The partnership is operated as a program of APCO International
- The purpose of the PSA is to ensure law enforcement, fire and EMS agencies are able to use the most technologically advanced communication capabilities
- The goal of the PSA is to raise awareness in Congress and the White House about what our Nation's public safety agencies need to build out a nationwide, interoperable, 4G, wireless communications network to protect America
- Website: http://www.psafirst.org/

DHS OEC

- **DHS OEC**: Department of Homeland Security Office of Emergency Communications
- Contributing to broad **policy** framework for public safety broadband
  - National Emergency Communications Plan (NECP) Addendum will identify key challenges and recommendations for integration of broadband technologies and data capabilities for tactical and operational use
- **Coordination** among stakeholder groups on broadband issues
  - Developing educational brochures and guidance documents
  - Developing strategies for broadband technology migration
- Developing, and aligning **grant policies and guidance** to address broadband deployment based on stakeholder input
- Providing **technical assistance** to waiver jurisdictions and other early adopters of broadband solutions

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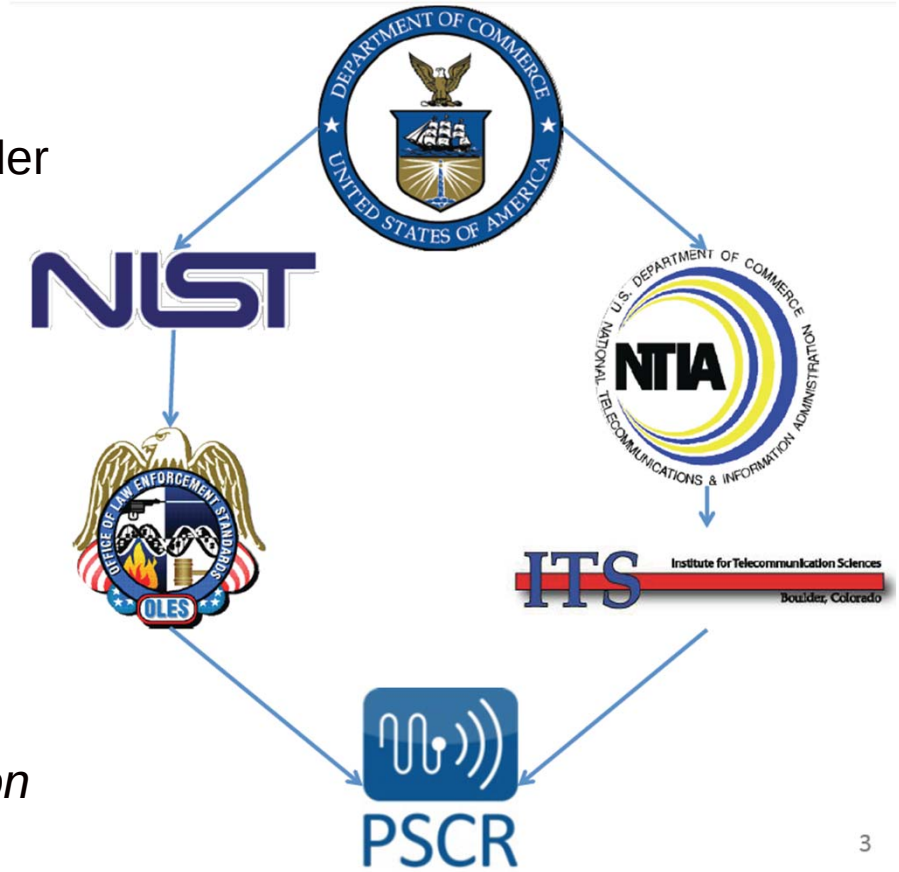
PSCR

- **PSCR:** Public Safety Communications Research, US Department of Commerce – Boulder Laboratories
- PSCR is a joint effort between NIST/OLES and NTIA/ITS
- Located in Boulder, CO
- *PSCR's mission is to act as an objective technical advisor and laboratory to public safety to accelerate the adoption and implementation of only the most critical public safety communication standards.*



PSCR Demonstration Network

- Collaborates with ERIC on research, development, testing, evaluation, and recommended guidelines, requirements and standards for public safety broadband
- Building a 700 MHz Demonstration Network in Boulder, Colorado as a neutral, multi-vendor test site for public safety broadband equipment
- Hosted 700 MHz Demonstration Network Stakeholder Meeting in Dec. 2010.
- Waiver recipients are required to certify that their vendors are participating actively in the Demonstration Network through submission of their equipment to be evaluated
- Website: http://www.pscr.gov/projects/broadband/broadband_about.php

Public Safety Communications Research
PSCR
U.S. Department of Commerce – Boulder Laboratories

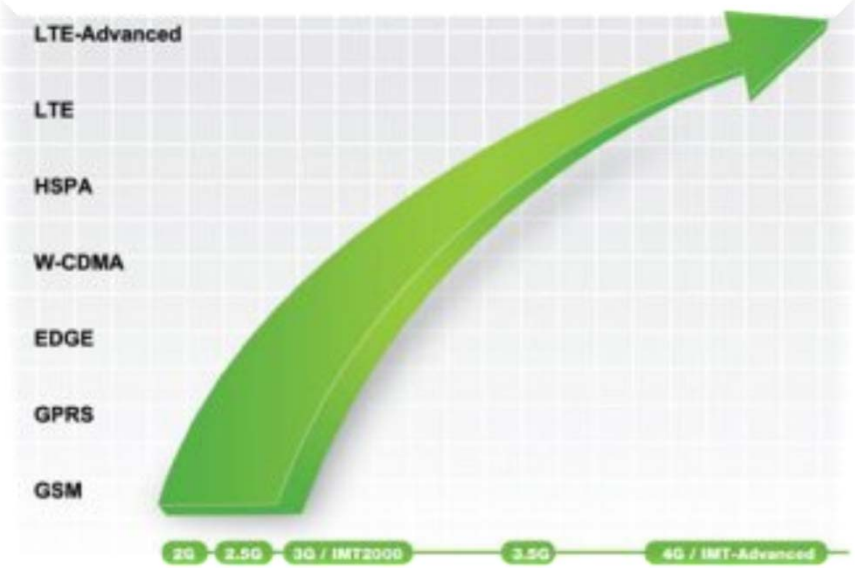
PSCR Study Item Groups

- PSCR has formed several study item groups for the 700 MHz Demonstration Network and is seeking participants:
  - 700 MHz UE Testing
  - Application Testing
  - Network Identifiers
  - Network Performance
  - Network Security
  - Quality of Service
  - Radio Access Network Testing
  - Roaming and Clearing
  - Universal Integrated Circuit Card (UICC) & universal sub. identity module
- http://www.pscr.gov/projects/broadband/700mhz_demo_net/study_item_resources.php

3GPP / ATIS

- **3GPP:** 3rd Generation Partnership Project
  - A global initiative that is developing the LTE standards
  - Proven track record with past developments and roadmap for continued developments
  - Major industry backing; thus, technology will be here to stay
- **ATIS:** 3GPP's North American Organizational Partner

▪Study Items are submitted to standards bodies
▪3GPP presently has a study item for direct mode (no infrastructure) for LTE
▪Websites:
http://www.3gpp.org/LTE
http://www.atis.org/3gpp/index.asp



Questions and Discussion

Technical Presentation to Follow

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LTE Comparison with Legacy Voice Land Mobile Radio (LMR)

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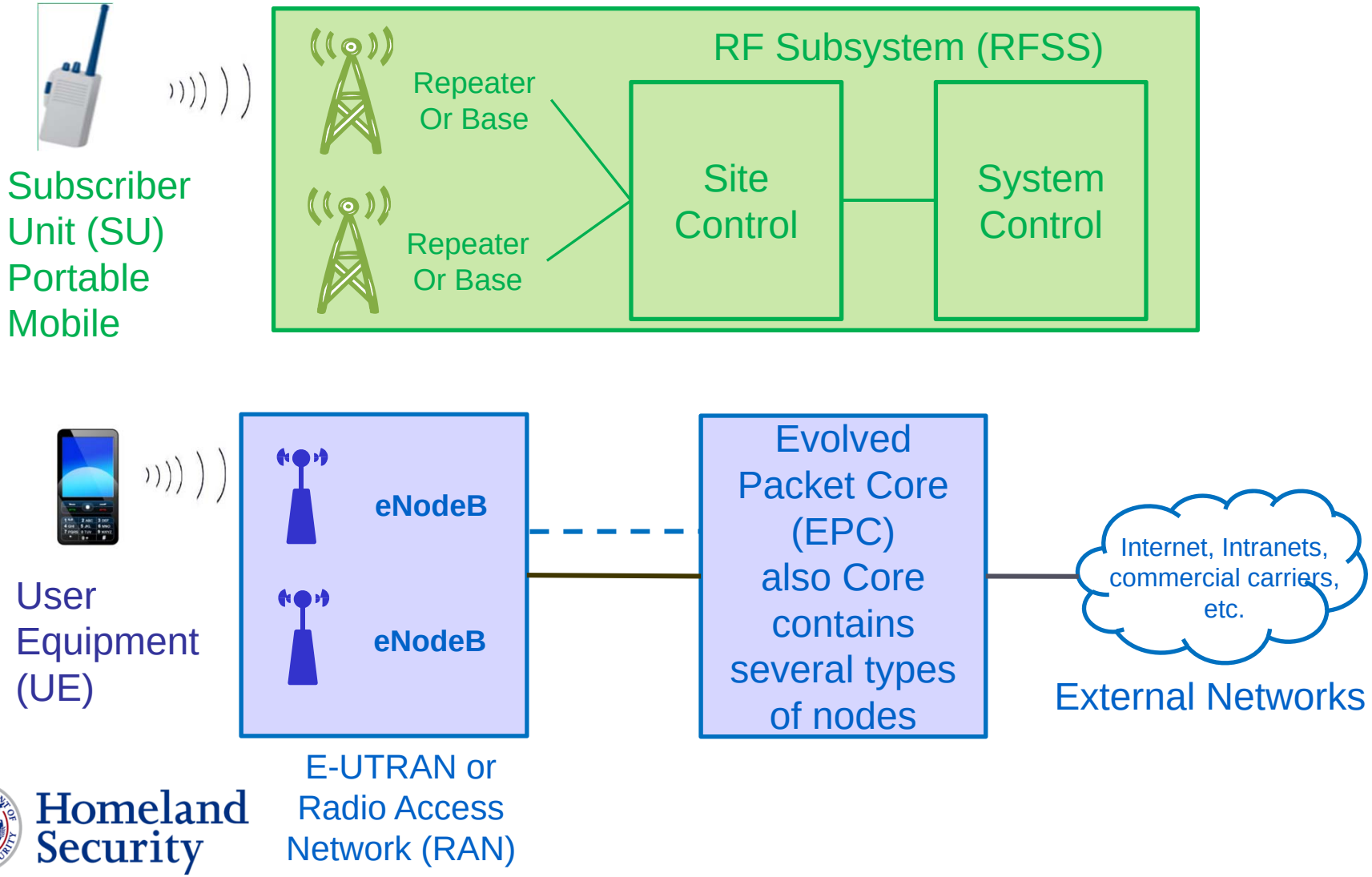
Rationale for Module

- This presentation compares LTE to a legacy voice system, principally FDMA P25 Phase 1
- The rationale is that comparison with something that is familiar will lead to a better understanding of LTE
- The comparison is with a voice system since everyone has a voice communication capability
- Some agencies also own or use a data system. Much of the comparison will apply to legacy data systems also.
- In this presentation legacy attributes will be colored **green** and LTE attributes will be colored **blue**

System Component Comparison



Application Comparison

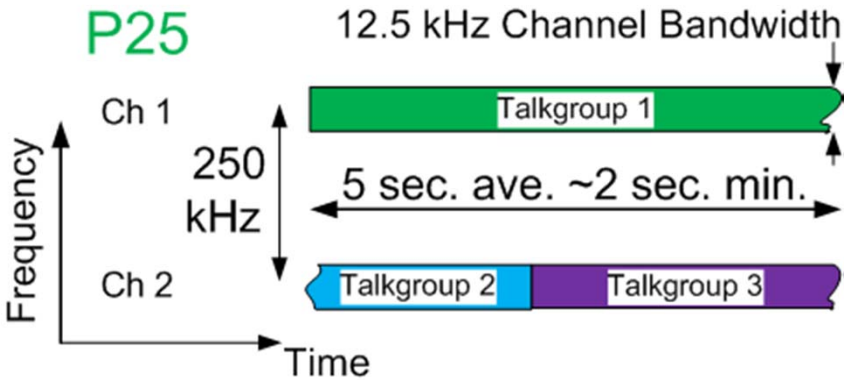
- Legacy systems:
  - P25: voice with ancillary use of tones, location reports, short text messages
  - 9.6 to 96 kb/s data only systems: database inquiries, mug shots, reports, CAD
- LTE is a high speed data system which can be used for many applications:

•File transfer
•Email
•Pictures
•Streaming video
•Text
•Voice
•Control (camera/robot/etc.)
•Building floor plan
•Computer aided dispatch (CAD)

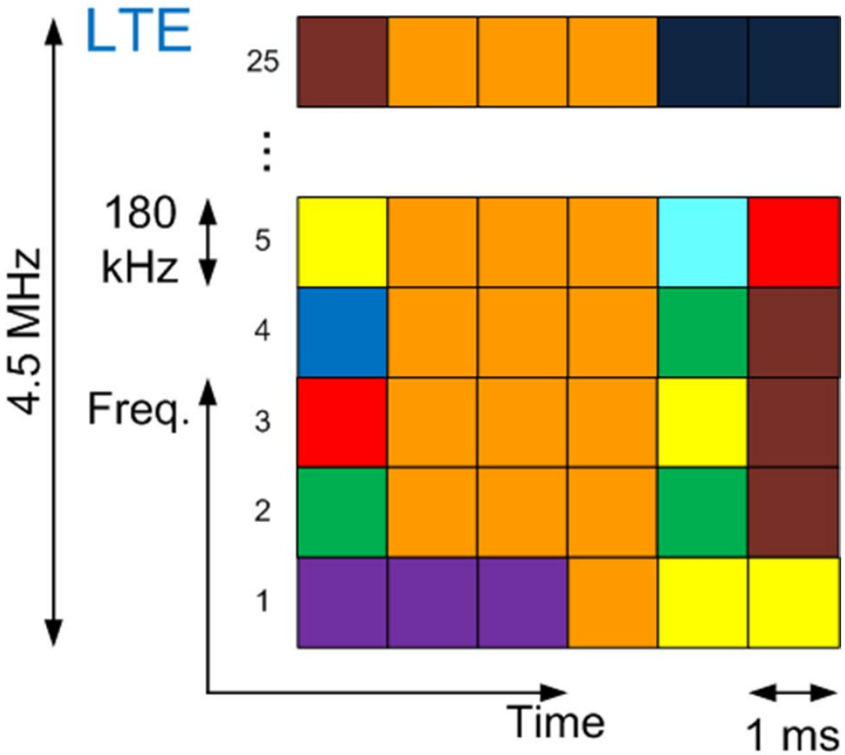
•License plate reader
•Fingerprint identification
•Facial recognition
•Scars, marks and tattoos
•Field Identification Cards
•Crowd sourcing & interactive maps
•Searching local, State and Federal data
•Child abduction leads tracking
•Multi-vital sign patient data transmission

The wide variety of applications available in LTE require application-specific modes of operation from the system as will be shown in subsequent slides

Channel Configuration at RF Site



- P25 sites use different frequencies at nearby sites
- P25 channels have 12.5 kHz bandwidth
- Separation between channels is usually 250 kHz or higher
- Talk groups are assigned a channel for the duration of a transmission



- All LTE sites use same frequency
- LTE channel is divided into resource blocks (180 kHz wide & 1 ms long)
- Resource blocks are assigned to be used by data sessions (denoted by color) as required

Figure of Merit

- Legacy voice is measured by delivered audio quality (DAQ)
- For example, DAQ 3.4 is defined as 'Speech understandable with repetition only rarely needed'. Occasional errors cause voice degradation but quality is acceptable.
- LTE can be measured by throughput in bits per second at the application level (data presented to user not control, overhead, etc.)
- For file transfer, text, and other similar apps, the user data must be free of all errors. Achieved by forward error correction, residual error detection and resending data packets until all are received correctly.
- For streaming video and voice some errors are allowed since often data packets can't be resent and some error is acceptable

User throughput is a much more complicated figure of merit than the straightforward DAQ of P25.

LTE Throughput Factors

- P25 voice throughput is fixed at 4,400 bits/second (4.4 kb/s)

In LTE, throughput can be increased by:

- Higher ratio of signal divided by interference plus noise (SINR)
- More resource blocks allocated to a communication session
- Higher bits per symbol modulation
- Higher forward error correction code rate (less redundant bits added to the bit stream)
- More complex form of receive and transmit antenna configurations

Each of these five LTE throughput factors will be discussed on the following slides

RF SINR

- DAQ 3.4 equates to a signal to interference plus noise ratio (SINR) of 17.7 dB for a P25 signal (-108.9 dBm for a RX sensitivity of -119 dBm)
- If signal level is higher the voice quality is better
- P25 is open loop – launch the signal and hope it is received
- LTE on the other hand has signal quality feedback
- Each UE measures the quality of signal received from the eNodeB and sends that information to the core.
- Likewise the LTE eNodeB measures the signal quality that is received from each UE.
- LTE uses signal quality measurements to dynamically adjust throughput – higher SINR area has higher throughput

P25 'wastes' high signal levels; LTE uses high SINR to improve performance dramatically = higher throughput

Throughput Optimization

- At high SINR, LTE will use a modulation with higher bits per Hertz, less overhead bits for error correction and will have to resend data less often. Thus, not only is the quality better but the throughput will increase substantially.
- Maximum throughput within a RF site may be 100 times the minimum
- Possible requirements for a system design:
  - Specify minimum acceptable rate. This is used to determine covered area – throughput rate at edge of coverage (edge rate)
  - Specify average throughput over covered area as a measure of how well the system is able to adjust parameters in response to signal quality to optimize throughput

P25 specifies coverage/performance with one minimum signal level. LTE must specify at least two performance metrics to ensure the optimum throughput is achieved.

SINR Limiting Factors (N or I?)

- Legacy voice systems are virtually always limited by noise
- Occasionally interference will be higher than noise and thus limit performance. For example:
  - Unusual weather conditions cause temporary interference
  - FCC licenses someone close enough to raise I + N level
  - Intermodulation products formed due to degradation of equipment
- LTE throughput will be limited by either or both. LTE throughput will always be limited by interference at the edge of cell coverage
- All cells use the same frequency band, e.g. 763-768 MHz, so at the edge potential interference from adjacent cell will limit freq. use

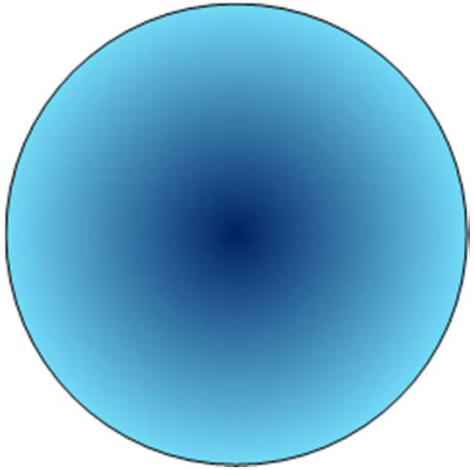
Due to LTE's use of the same frequency for all cells/sectors interference must be controlled on a site by site basis

Frequency/Bandwidth Assignment

- Frequencies for P25 systems are assigned by the FCC to minimize interference at the edge of coverage
- For LTE the FCC assigns entire band to a licensee who then is responsible for minimizing interference internally & with neighbors
- UE with strong signals can be assigned to the entire bandwidth, if needed, since its signal is so much higher than interference from adjacent cells using the same frequency
- UE with weak signals must be assigned to a unique set of subcarriers that isn't used by nearby cells since a small amount of interference could reduce the already low SINR. This could reduce throughput for these UE.

A properly designed LTE system that uses all the tools of the standard can greatly improve spectral efficiency by adaptive assignment of frequencies in the band.

LTE Throughput vs. Covered Area - Idealized RF Propagation Examples



This is an idealized site using an omni-directional antenna. Higher throughput (darker area) occurs close to the antenna (center of circle).

A site with 3 sectors of 120 degrees. Higher throughput occurs close to the antenna of each sector. Throughput is lower in the overlap between sectors due to potential interference from the adjacent sector. For UE in overlap area, adjacent sectors can't use the same resource blocks (same frequencies at the same time).

Modulation Type

- P25 employs a fixed 2 bits per symbol (4 level) modulation
- LTE employs 2, 4 or 6 bits per symbol modulation
- The higher bits per symbol modulations require a higher SINR.
- Selection of modulation type can be adaptive
- If a UE has a high SINR it can be assigned to use a higher bits per symbol modulation and thus improve throughput
- 6 bits/symbol can transfer 3 times as many bits as 2 bits/symbol using the same bandwidth and transmit time

LTE maximizes the throughput by increasing the bits/symbol to match the available SINR

Forward Error Correction

- P25 employs a fixed FEC rate to reduce errors to an acceptable level (voice at DAQ 3.4 has residual errors)
- LTE can adaptively choose an FEC rate to match the SINR
- Higher rate codes (less redundant bits added and therefore higher throughput) can be used when SINR is high and errors are few
- Lower rate codes (more redundant bits added to the user data) can be used when SINR is low and there are many errors that must be corrected (lower throughput)
- Some applications (e.g., a file transfer) cannot have any errors. Data must be resent if errors are detected after correction. Resending reduces throughput.

The adaptive ability of LTE results in higher spectrum utilization; redundant bits are only added in the quantity required

Antenna/RF Configuration

- P25 uses a single transmitter and receiver and single antennas for SU and base. The antennas usually have an omni-directional pattern.
- LTE provides for multiple transmitter and receivers and multiple antennas in a single UE and a single eNodeB (eNB). This allows for multiple input/multiple output (MIMO) operation.
- If SINR is high enough eNB can transmit two unique data streams from two antennas with spacing between them, and UE can receive both streams using two antennas and two receivers, thus increasing throughput. Throughput will not double. Also can be 4 level MIMO.
- Likewise, the same data stream can be transmitted and received at the same time using multiple paths to decrease error rate
- Multiple antennas at transmitter can beam power to UE
- Directional antennas can direct energy to a pie shaped sector of a site. Each sector (often 3) provides capacity to UE in its area and antenna gain is high.

LTE is designed to increase capacity or increase signal level by the use of multiple data paths or directional antennas

RF Coverage Area

- LTE will cover less area than P25 in the same frequency band for several reasons:
  - Lower RF power (40 Watts from base, 0.2W from UE)
  - For the same RF power level a higher data rate (higher bits/second) results in less energy per bit: 10*log(9.6 kb/s/320 kb/s) = -15 dB
  - Internal antenna on handheld may be less efficient than external
  - Zero final errors for some applications requires higher SINR
- How much less area is dependent on many factors:
  - High throughput at edge of coverage requires high SINR
  - Requirement of both high average data rates and high usage in all cells will increase noise levels and cause high modulation modes, and thus require higher signal levels

Comparison of Coverage per RF Site (700/800 MHz)

System	Type	# of Sites	Area (square miles)	Area/site
Arkansas	P25	72	53,179 (State)	627
Louisiana	P25	100	43,561 (State)	414
Michigan	P25	231	58,804 (State)	239
San Diego	SmartNet	36	4,526 (County)	126
Adams	LTE	15	1,198 (County)	80
BayWEB	LTE	193	7,370 (10 Counties)	38
LA County	LTE	300	4,061 (County)	14

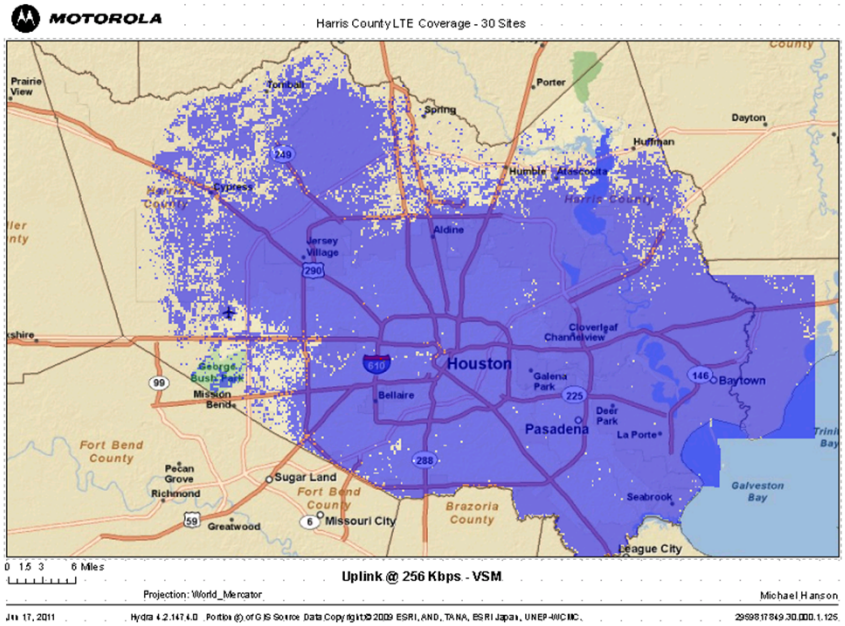
Initial LTE designs indicate coverage per RF site will be substantially less than P25

Direct comparisons are needed – same location & UE configuration

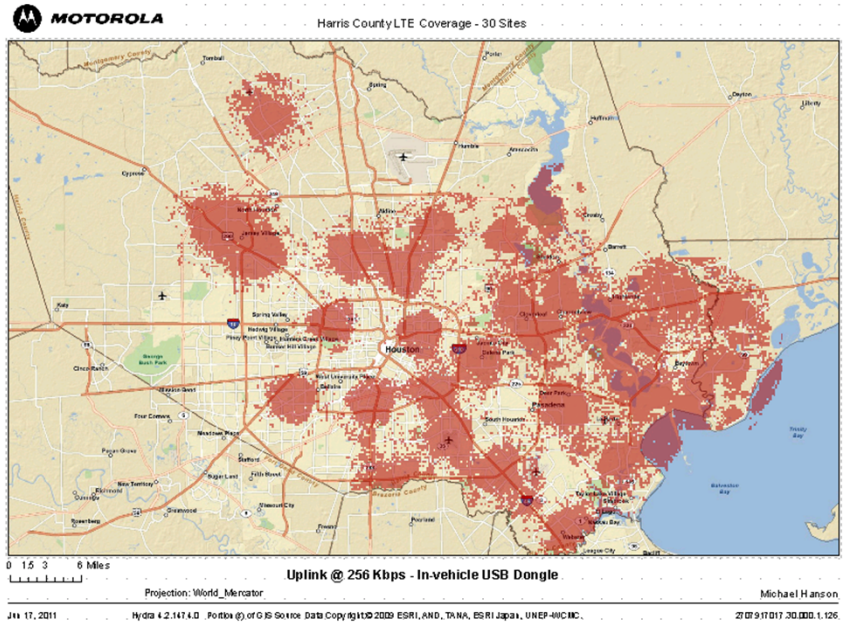
LTE Coverage – UE Comparison

Source: Harris County Interoperability Showing

Vehicular modem with antennas on exterior - Uplink



USB dongle inside vehicle – Uplink = UE dongle to eNB



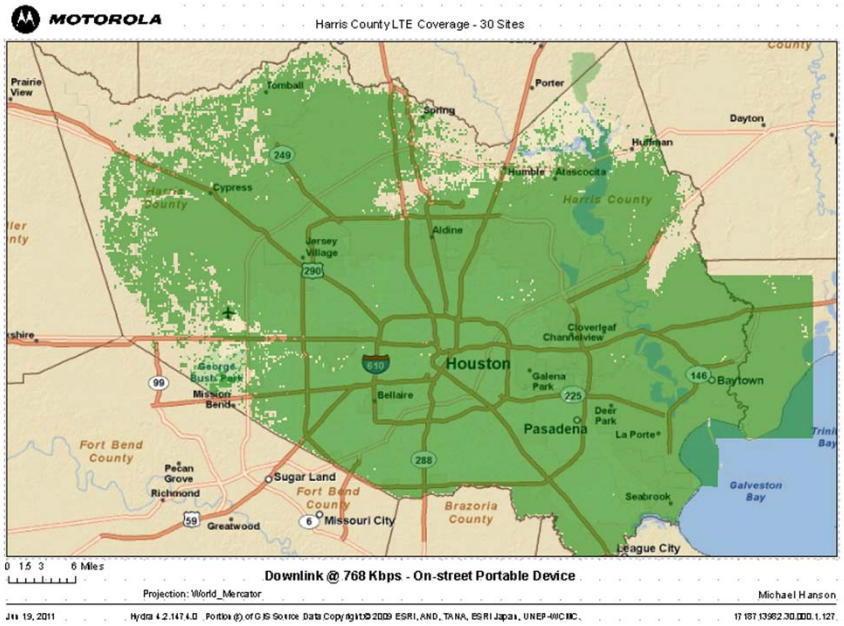
Just as in P25 type and position of UE will have a large effect on coverage

Coverage shown is for 30 sites – current plan is 16

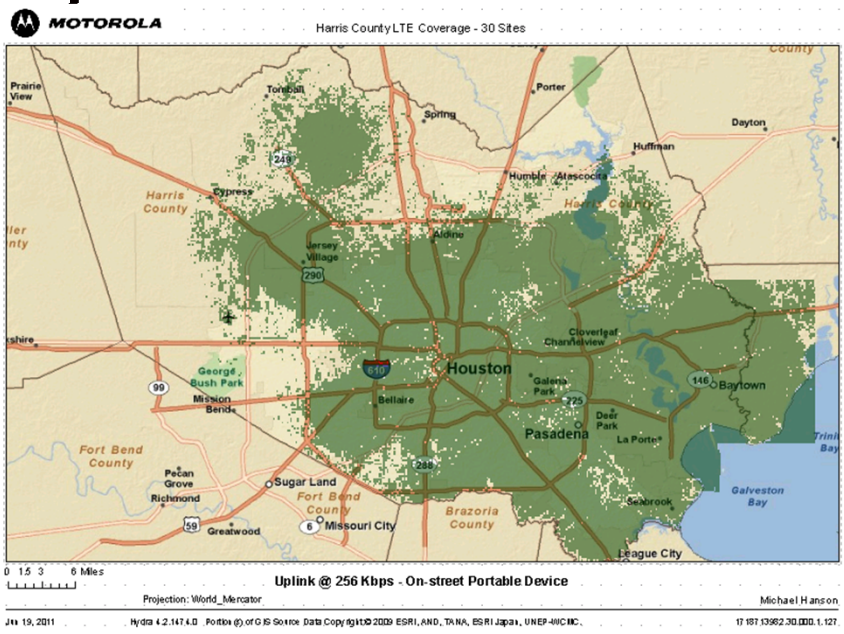
LTE Coverage – Uplink/Downlink

Source: Harris County Interoperability Showing

Portable on street – Downlink at 768 kb/s



Portable on street – Uplink at 256 kb/s



Low RF power of UE (0.2W) will limit uplink coverage relative to downlink

Coverage shown is for 30 sites – current plan is 16

Multicast and Unicast

- P25 systems make heavy use of multicast (one-to-many) group voice calls and occasionally broadcast (one-to-all)
- Some P25 systems prohibit unicast (one-to-one) calls due to their inefficiency in the use of spectrum – people tend to talk longer
- P25 data is presently limited to one-to-one
- LTE is primarily a one-to-one data service
- LTE has a mode called multimedia broadcast multicast service (MBMS) which provides one-to-many/all for data
- MBMS could be extended to voice using voice over IP (VOIP) as a data stream, thus allowing group calls
- Included in Release 9 of LTE – implementations are R8

Implementing MBMS in LTE would improve the efficiency of a public safety network that is reliant on group calls

Simulcast

- A simulcast subsystem transmits the same information on the same frequency from sites whose coverage overlaps
- Simulcast is used for its spectral efficiency and the ability to roam from site to site without having to re-affiliate
- P25 makes heavy use of simulcast especially in urban areas
- P25 sites configured for simulcast are always simulcast
- LTE has a simulcast mode called multimedia broadcast over a single frequency network (MBSFN) – subset of MBMS
- MBSFN can be allocated as needed at whatever sites it is needed; otherwise, those sites are unicast – very flexible
- Efficient method to send lots of data to many users at the same sites; e.g., streaming video of a robotic camera

Both have simulcast but LTE may not be offered initially. LTE is more flexible in its use

Latency

- P25 specifies that the delay for voice from mouth to ear shall be less than 350 milliseconds (ms) for a trunked system
- LTE is designed for very low latency so that it can support voice and gaming applications
- LTE round trip delay for data is 10 ms or less for a pre-scheduled link and 25 ms or less for an on-demand link
- Voice delay will be longer than this to allow for capturing a voice frame (might be 20-40 ms) but it can be substantially less than P25
- Low latency of LTE will allow near real time remote control

Subscriber Unit Provisioning

- P25 subscriber units (SU) are programmed by connecting them to a computer and using specialized software that is different for each vendor and often different for models from same vendor
- Over-the-air programming is available but is not standardized
- LTE makes use of Universal Integrated Circuit Cards (UICC)
- UICCs contain information about the user and the networks that the user is authorized to access and contact lists, etc.
- UICCs are standardized to work in UE from different vendors
- A public safety user could move the UICC to different UE as needed. The user's identity and network access would follow it.
- A central clearing house could issue UICCs for the entire Nation
- UE can be programmed by the user by subscribing to services
- An application could allow a dispatcher to add services to UE
- There are standardized protocols for over-the-air programming

Security

- P25 requires encryption provisioning (key fill) by physically connecting to a SU. Further provisioning can be performed over-the-air if so equipped.
- P25 provides 256-bit AES encryption that meets FIPS 140-2
- P25 does not encrypt the control data
- LTE has standardized encryption using a 128-bit key but it isn't end-to-end. Data is encrypted/decrypted at the eNodeB.
- LTE encrypts both the user data and the control data
- May need application layer encryption for adequate security level and for true end-to-end security to meet Federal and state requirements
- A virtual private network (VPN) will be necessary

Voice Communications

- Low latency voice communications requires many small packets of data sent in a continuous stream
- P25 is optimized for voice with 9.6 kb/s gross data rate
- LTE is IP-based end-to-end and optimized for high data rates using large packet size. Small IP packets are not efficient.
- Scheduling many small packets for each of many voice channels could overwhelm the LTE control channel
- Voice should be treated differently than other data in LTE
  - Compression of IP header to improve efficiency
  - Semi-persistent scheduling of data (that is, periodic packets) can be scheduled once, not once for each packet (implementing?)
  - Bundling of small packets to decrease error rate at cell edge

Voice over LTE requires unique processing which must be standardized

Types of Voice Communication

- LTE doesn't directly support any voice communications presently but there are several efforts in progress:
- Duplex Voice over IP (Telephone calling)
  - IP Multimedia Subsystem (IMS) - eventual goal
  - VoIP over LTE (VoLTE) is being developed as a subset of IMS
  - Could be based on telephone #'s or IP addresses
  - Several demonstrations have been conducted
- Push-to-talk (PTT) Non-mission-critical
  - Not all the features public safety requires & slow access
  - Examples: Motorola PTT (Verizon) & Kodiak RTX (AT&T) & IDEN (Sprint/Nextel & SouthernLINC), BeOn from Harris
  - Demonstrations have been conducted with LTE PTT communicating with P25 PTT using the ISSI to connect the two systems.

Telephony and non-mission-critical PTT voice could be implemented soon on a public safety LTE system

Mission-Critical Voice

- P25 and legacy systems provide mission-critical PTT voice now
- Could be years before LTE can support mission-critical PTT voice
- NPSTC has produced a description of mission-critical voice for LTE
- Some of the salient requirements of the functional description follow:
  - "Immediate" communications with low call setup times
  - Direct (no infrastructure required) communication mode
  - PTT, half duplex, group or individual call
  - Duplex telephony
  - Emergency call with ruthless preemption & audio takeover
  - Audio quality such that no repetition is needed, speaker recognition, speaker stress level in voice, background sounds can be heard with sufficient clarity
- Intend to send description to standards body for incorporation in LTE
- Direct mode has been requested from standards body (3GPP)

It may be years before mission-critical voice is available in LTE. Direct mode may be implemented outside LTE.

In-Building RF Coverage

- P25 uses bidirectional amplifiers and distributed antenna systems (DAS) to boost signal into RF-opaque buildings
- LTE could use these same techniques but it also could use femto-cells (Home eNodeB in LTE) or picocells
- These cells are small, low RF power devices that provide coverage to a small area. Picocells cover a larger area and serve more users.
- These cells are usually connected to the backhaul network through a wired IP connection so generally no RF antennas are required on the outside of the building
- These cells are easier to install than DAS. They are almost plug&play
- These cells increase not only coverage but throughput

RF Power Envelope

- RF signals that do not have a constant envelope (peak to average power ratio (PAPR) > 1) cause transmitters to consume more power, be larger and more expensive
- P25 is constant envelope except simulcast and Phase 2 downlink are non-constant envelope
- LTE downlink has high PAPR due to amplitude modulation modes and the combination of multiple subcarriers
- LTE uplink has been designed to have less variation (lower PAPR) to increase battery life and reduce size of UE

The high PAPR of LTE is a significant factor that increases the size, power consumption and cost of LTE transmitters

Battery Life

- P25 handheld are typically specified for 8 hours or more life at a duty cycle of 5% transmit, 5% speaker on, 90% standby
- P25 SU always transmit at full power (e.g. 3 Watts)
- P25 SU always have receiver turned on even in standby
- P25 handhelds have large, heavy batteries
- LTE handhelds for public safety do not have battery life specs yet. A public safety duty cycle must be defined.
- LTE UE have 0.2 Watts max. transmit power and it can be reduced further by power control
- LTE can turn the receiver off for a large percentage of the time – wakes up periodically to check for messages

LTE has features that minimize battery energy consumption.
LTE public safety battery life is undefined at present time.

Priority and Quality of Service (QoS)

- P25 has multiple levels of priority that can be assigned to talkgroups and types of calls (e.g., emergency call)
- Because of the many different applications (not just voice), LTE uses a QoS metric which includes priority and other factors such as guaranteed bit rate (or not), packet delay budget, and packet error loss rate
- QoS is assigned to each UE on a bearer (application) basis. A UE may have a different QoS for voice than for queries.
- PSCR & NPSTC have groups to formulate QoS practices
- For example: Can a local operator configure QoS in response to an incident in an area to ensure that the most important communications are realized whether the users are local or roamers?

Capacity

- P25 defines a voice traffic profile for the average user by discipline that includes number of voice calls during busy hour, average length of call and number of RF sites transmitting per call
- Profile is used statistically or empirically to determine the number of allowable users given an acceptable delay in granting a channel
- LMR has a long history of measured profile patterns
- The profile for LTE must include allocations per user and discipline for each of the many applications the user may access, some of which may be simultaneous
- Public safety will need to build user data profiles without the benefit of a rich history of examples
- Capacity will vary within a cell – higher where SINR is high
- For one-to-one sessions adding sites increases capacity

Summary

- LTE will be the most extensive technical change public safety communications has experienced
- It also has the potential to provide the most productive change in the history of public safety communications
- One of the key attributes is the ability of the system to use all the various modes to match the throughput to the available SINR for all active UE whether near the site or at the edge

Homeland Security

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