The Market Opportunity for LTE at 700MHz

December 3, 2008

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A quick introduction to Signals Research Group, LLC.

- Signals Research Group, LLC offers thought-leading field research and proprietary consulting services on the wireless telecommunications industry.
- Our flagship research product, a research newsletter entitled “Signals Ahead,” includes more than 70 corporate subscribers on five continents across the entire wireless ecosystem, as well as trade organizations, government regulatory bodies, and organizations within the financial community.
- Historically, nearly half our business each year falls outside of the Signals Ahead business area.

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700MHz Engineering Challenges

LTE Myths

LTE and 700MHz: Western Europe Case Study

Auction 73: US Case Study

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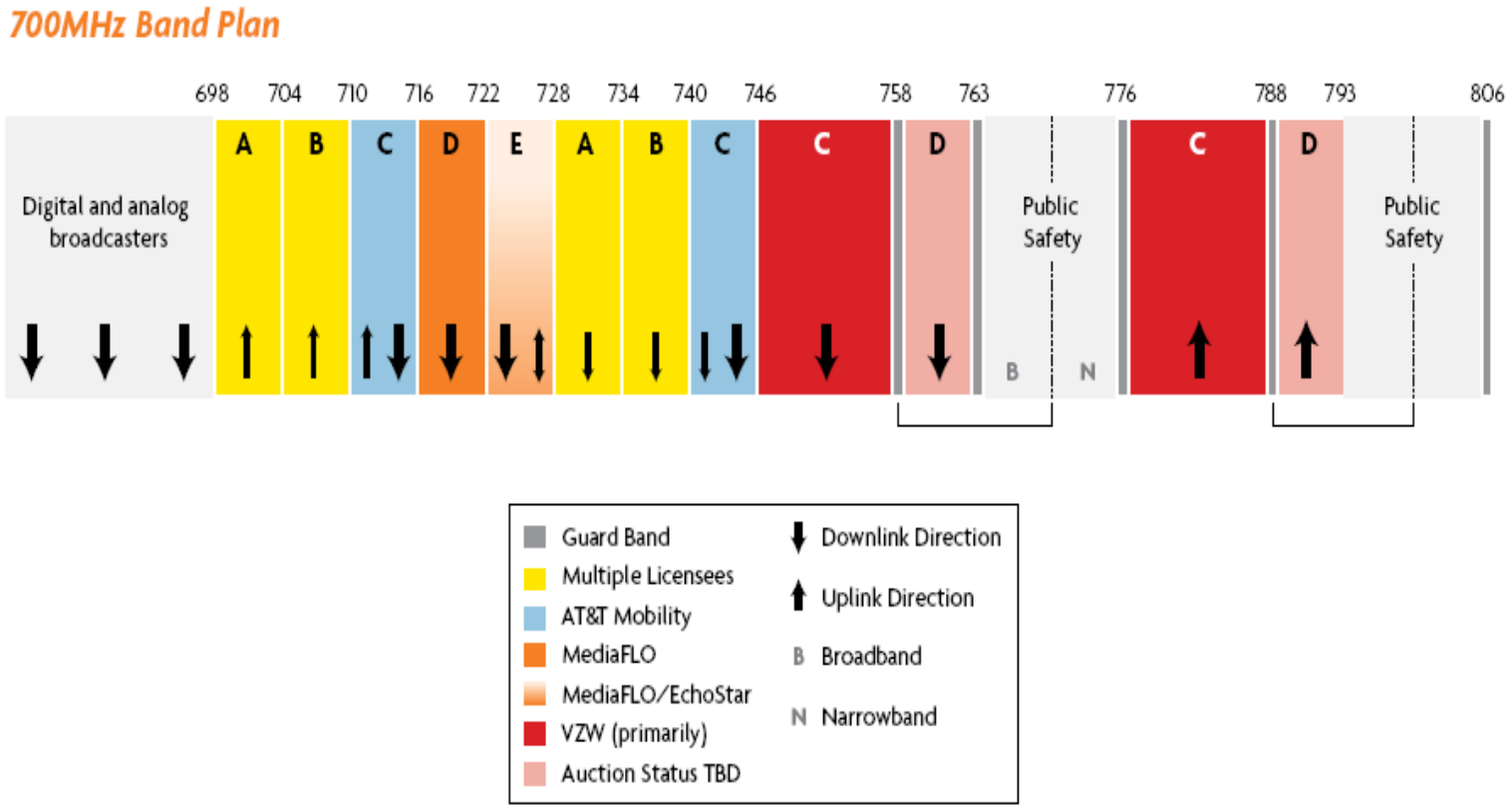
Although 700MHz is “beach front property” it does come with its share of challenges for some (or opportunities for others)

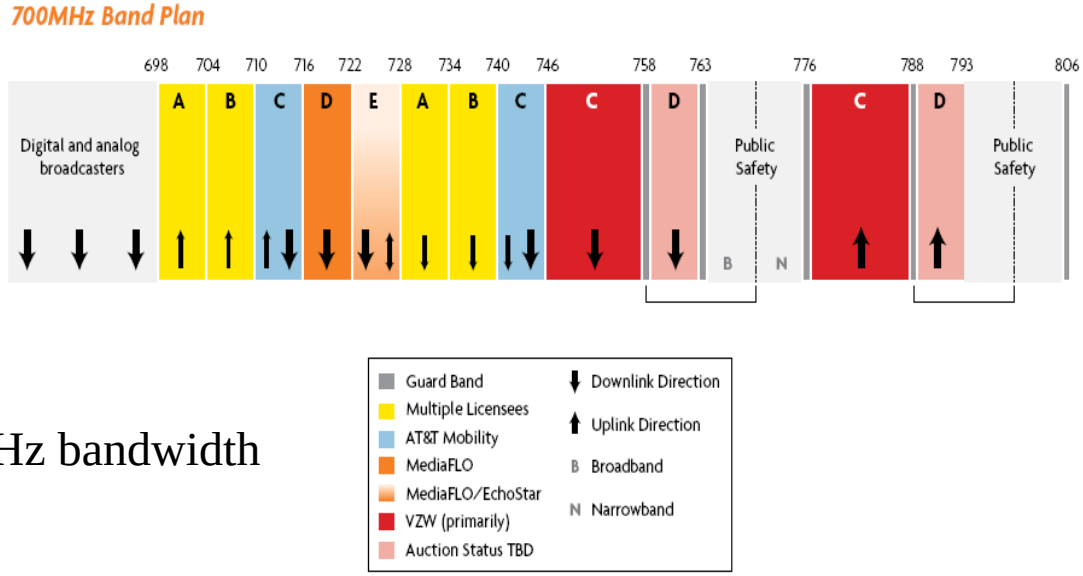


Source: FCC and Signals Research Group, LLC

- Narrow channels and the general lack of spectrum
- MIMO implementations
- Interference with broadcasters
- Self-interference
- Interference with public safety

Narrow channels and the general lack of spectrum

- The lower A-C blocks are limited to a pair of 6MHz channels.
  - 1 HSPA/HSPA+ carrier
  - 3 EV-DO carriers
  - 1 5MHz OFDMA carrier



Source: FCC and Signals Research Group, LLC

- OFDMA is most efficient with >10MHz bandwidth allocations
  - 5-30% penalty in overall throughput
  - A 5MHz LTE carrier offers little performance advantage over HSPA+

- Operators are essentially forced to use an N=1 frequency reuse scheme.
  - Interference increases, thus impact throughput and the average user experience
  - Sprint Nextel/Clearwire use N=3
- General consensus among operators is that they will still deploy LTE, although they haven't ruled out other technologies.
- Most operators can combine blocks to create a 10MHz (N=1) radio carrier.

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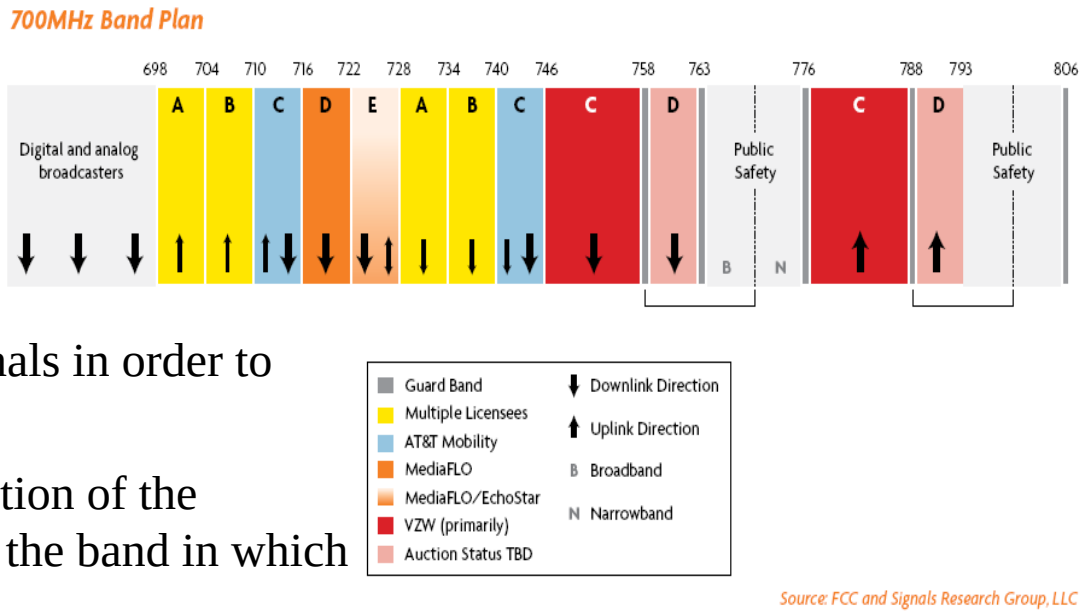
MIMO Implementations

- In theory, MIMO can lead to a doubling of user data rates and spectral efficiency.
  - ~20% improvement over 2-Rx



- MIMO requires highly decoupled signals in order to achieve maximum effectiveness.
- The size of the antenna and the separation of the antennas are inversely proportional to the band in which they are operating.
- 4x4 MIMO is even more challenging than 2x2 MIMO.
  - Antennas (and potentially MIMO) could be required for other bands as well (e.g., 1700MHz).
- A single 700MHz antenna cannot efficiently cover the entire band (e.g., A Block through upper C Block.
- Operators are still pushing their vendors to support MIMO although there could be some devices that don't support it (or don't support it very well).

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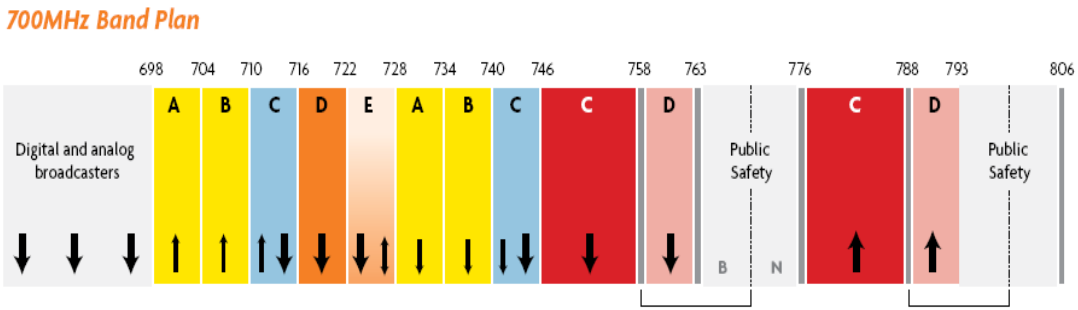
Interference with broadcasters, one's self and public safety

- TV broadcasters can create interference with the A Block licensees.
  - only in certain markets



Source: FCC and Signals Research Group, LLC

- MediaFLO (D Block and E Block) sits adjacent to the lower C Block and the A Block.
  - AT&T Mobility has sole rights to the lower C Block
  - E Block is even more challenging
- Issue will be most evident when desired signal is weak and undesired signal is strong.
- The gap between the transmit and receive bands is very narrow relative to most frequency bands.
  - Minimum gap is 12MHz for the upper C Block and 18MHz for the lower A-C Blocks
- One potential solution would be to limit the number of resource blocks assigned to a user, thus degrading performance
- The upper C Block can interfere with the D Block (public safety) with one proposed solution resulting in a reduced maximum device transmit power.

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Contrary to popular belief, there isn't a discernable economic benefit of LTE relative to other advanced 3G technologies (e.g., HSPA/HSPA+).

- After normalizing for bandwidth requirements, the relative performance differences between LTE and HSPA/HSPA+ are not "day and night."
  - LTE theoretical peak data rates are achieved through MIMO and wide radio carriers
  - LTE spectral efficiency is only ~25% higher than HSPA+ (w/ MIMO and 64-QAM)
- The cost drivers in next-generation broadband wireless networks are due to factors other than the choice of technology.
  - Design criteria of the network
  - Choice of frequency band
- Many of the cost advantages associated with LTE can be realized with a CDMA-based 3G network.
  - Flat-IP core network versus hierarchical network
  - All-IP backhaul and transport (Ethernet, etc) versus leased T-1/E-1 lines

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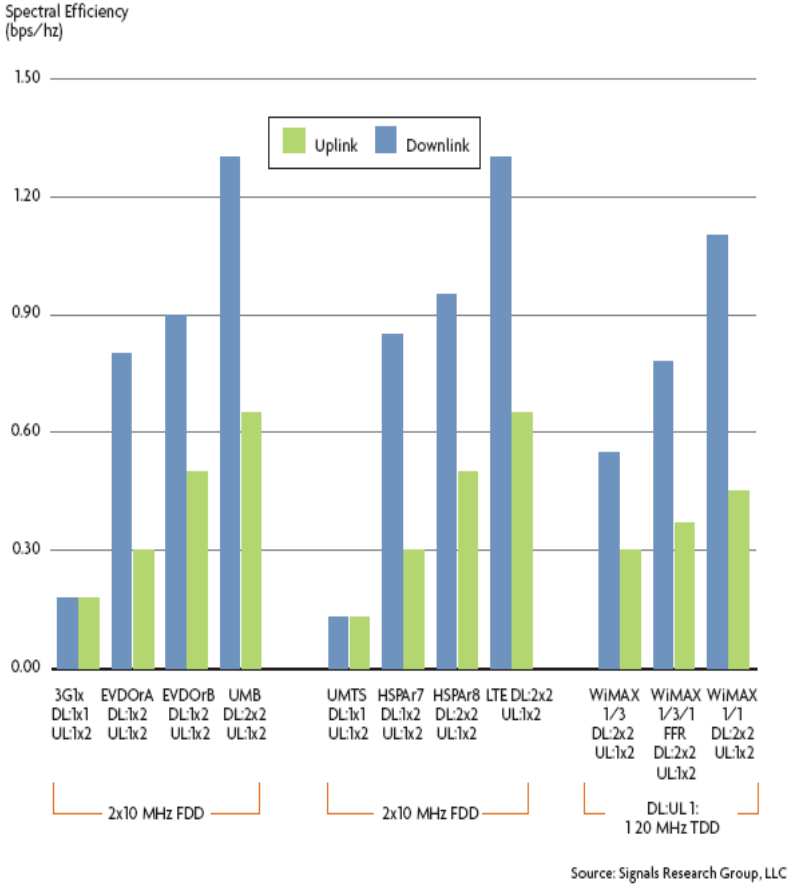
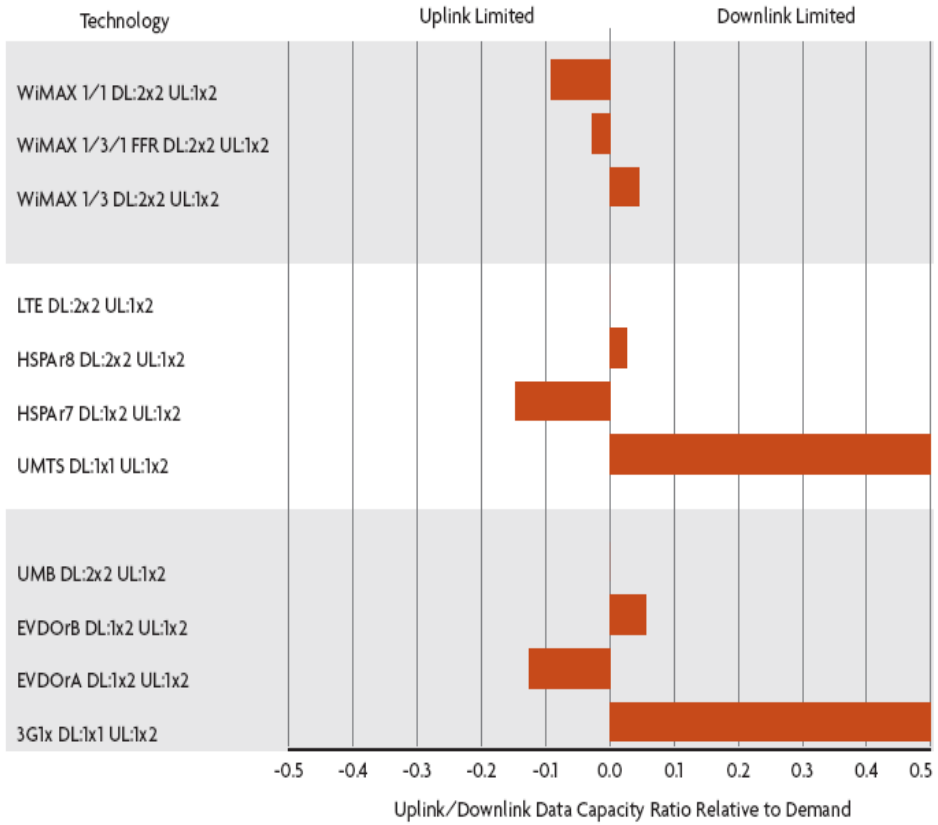
Spectral Efficiency Assumptions for Next-generation Wireless Technologies

Full Buffer Layer 2 Spectral Efficiency



Source: Signals Research Group, LLC

Uplink/Downlink Data Capacity Ratio Relative to Demand



Source: Signals Research Group, LLC

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Service Concepts: Statistical Performance Expectations

Service Concept	Voice	Data	Mobility	Antenna	Voice Probability of Coverage	Uplink Data Rate/Probability of Coverage
1	Yes	Yes	Mobile	Integrated	90%	90% @ 128kbps
2	Yes	No	Fixed	Desktop	90%	
3	No	Yes	Fixed	Desktop		80% @ 256kbps
4	Yes	Yes	Fixed	Desktop	90%	80% @ 256kbps
5	Yes	No	Fixed	Window	95%	
6	No	Yes	Fixed	Window		85% @ 256kbps
7	Yes	Yes	Fixed	Window	95%	85% @ 256kbps
8	Yes	No	Fixed	Outdoor	98%	
9	No	Yes	Fixed	Outdoor		90% @ 512kbps
10	Yes	Yes	Fixed	Outdoor	98%	90% @ 512kbps
11	Yes	Yes	All of the Above	Any of the Above	Any of the Above	Any of the Above

Source: Signals Research Group, LLC

- A “Service Concept” (SC) is a function of the device type, the quality of coverage requirement and the types of traffic that the network supports.

- Broadly speaking, there are 4 Service Concepts: Mobile, Nomadic, Semi-fixed and Fixed.

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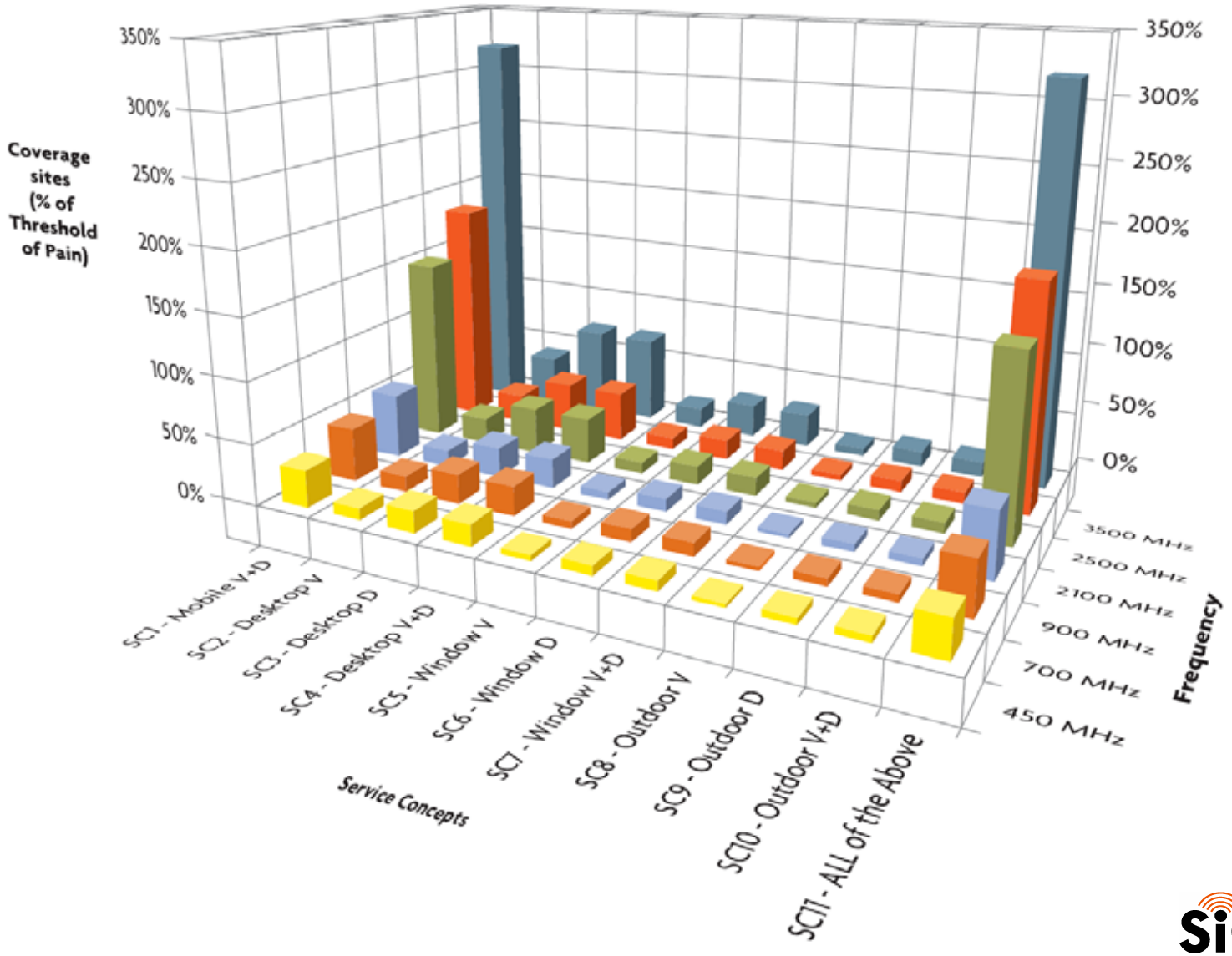
View of the World – Sites Required for Coverage



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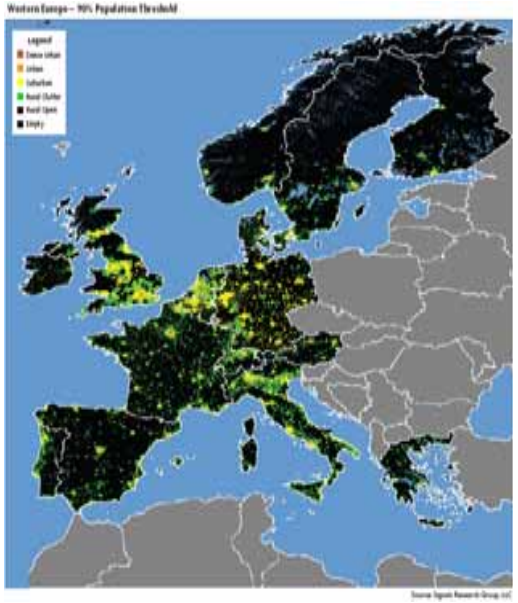
LTE Case Study – Western Europe



Our analysis of the current demographics and demand for telecommunications services in Western Europe suggests the following metrics:

- Population: 398,371,760
- Landmass: 3,698,112 square kilometers
- % of population living in dense urban, urban and suburban regions: 55.01%
- People/Household: 2.4
- Cellular subscriptions (individuals) per POP: 106.5%
- Landline subscriptions (households or businesses) per POP: 53.4%
- Broadband subscriptions (households or businesses) per POP: 23.2%
- Dial-up subscriptions (households or businesses) per POP: 11.5%
- Total cellular voice minutes per month: 5.25 billion
- Total wireline voice minutes per month: 3.82 billion

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LTE Case Study – Key Assumptions

Key Assumptions

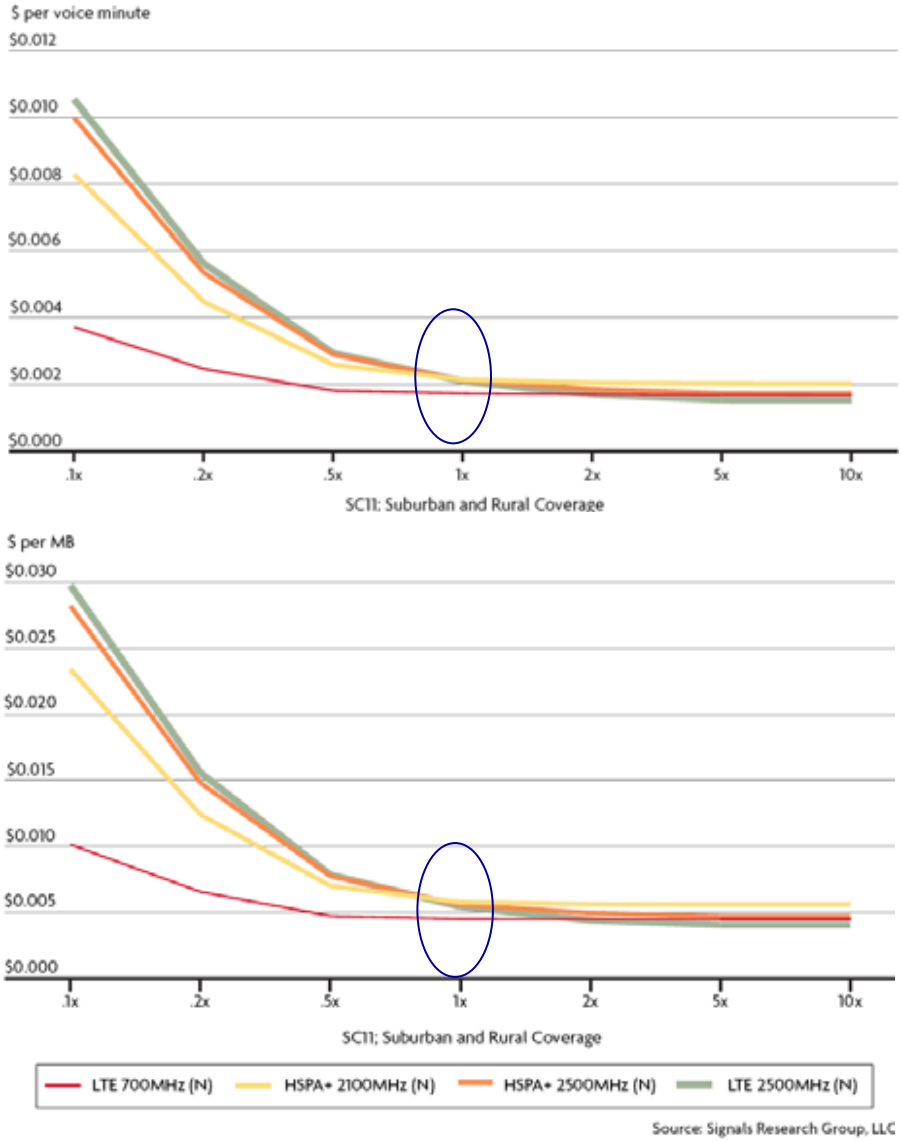
Technology	Deployment	Frequency Band	Channel Bandwidth	Total Spectrum	Core Network	Transmission	RRH
LTE	Network Overlay	700MHz	10MHz FDD	20MHz	Flat IP	Microwave/ Ethernet	Y
HSPA Evolved	Network Overlay	2100MHz	5MHz FDD	20MHz	Flat IP	Microwave/ Ethernet	Y
HSPA Evolved	Network Overlay	2500MHz	5MHz FDD	40MHz	Flat IP	Microwave/ Ethernet	Y
LTE	Network Overlay	2500MHz	10MHz FDD	40MHz	Flat IP	Microwave/ Ethernet	Y

Service Concept	11
Device Type	PC card
Quality of Coverage	128kbps with 90% PoC
Population Covered	259M (S and R)
Coverage Region	766,214 sq km

Source: Signals Research Group, LLC

- LTE and HSPA+ networks are deployed, covering the suburban and rural regions of Western Europe.
  - Choice of frequency band and the amount of spectrum varies by network strategy
- All network strategies take advantage of advanced features, such as an IP core network and Remote Radio Heads.

LTE Case Study – Results ($/Min and $/MB) as a function of demand



- At low demand levels, the network strategies involving LTE are the most attractive and the least attractive options.
  - Networks are all coverage-constrained so the advantage/disadvantage is largely a function of the choice of frequency band
- As demand [network traffic] increases the merits of LTE at 2500MHz become more attractive.
  - The economics of LTE at 2500MHz are roughly on par with the economics of HSPA+ at 2100MHz, starting at today's demand levels.

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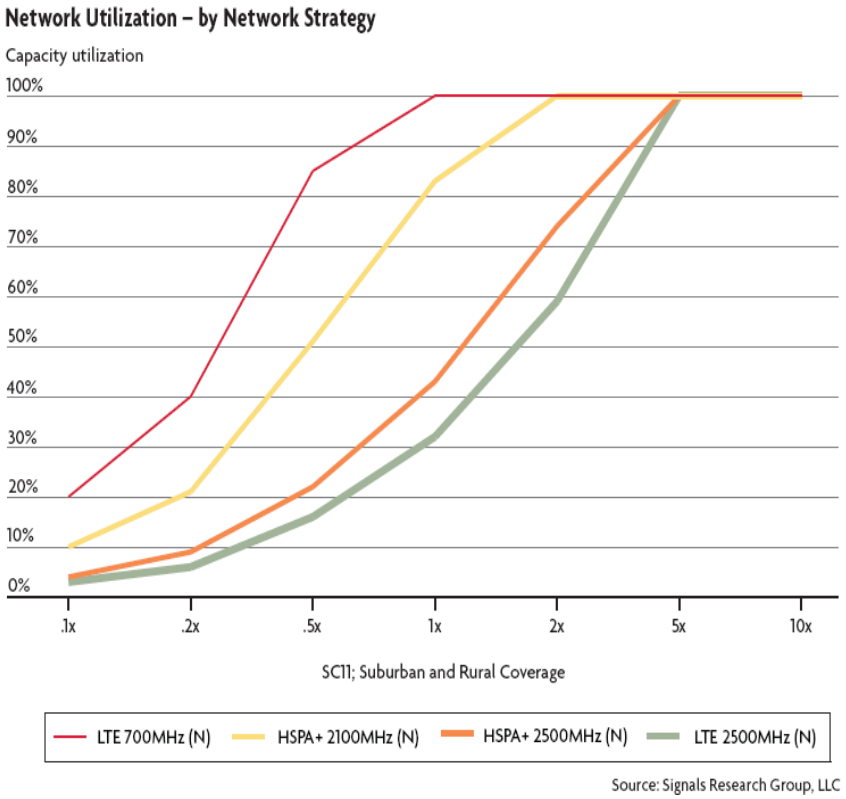
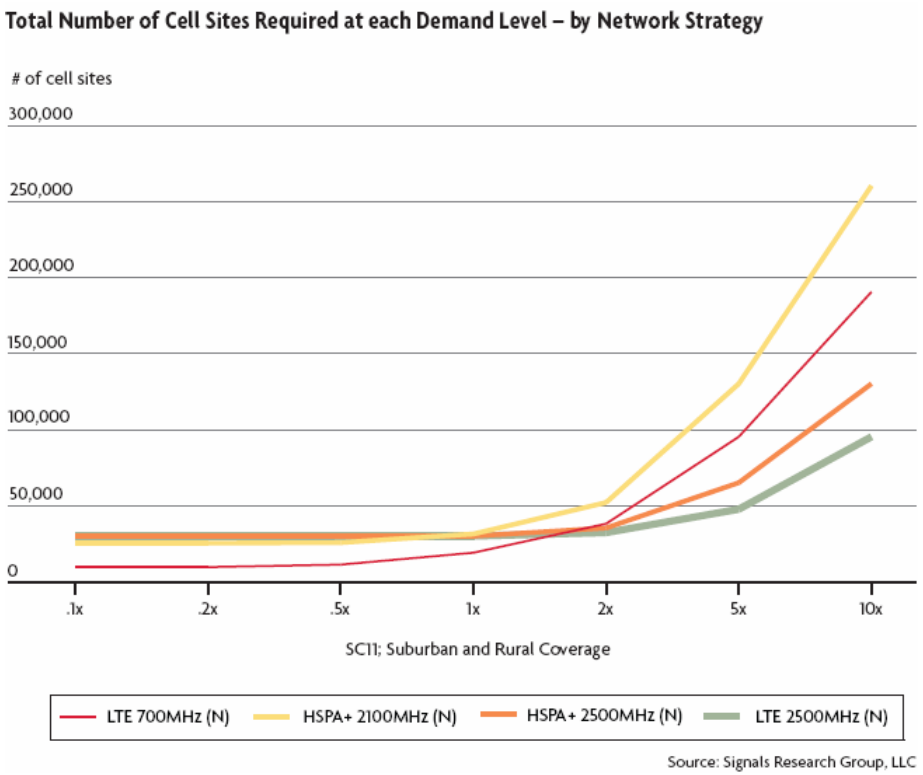
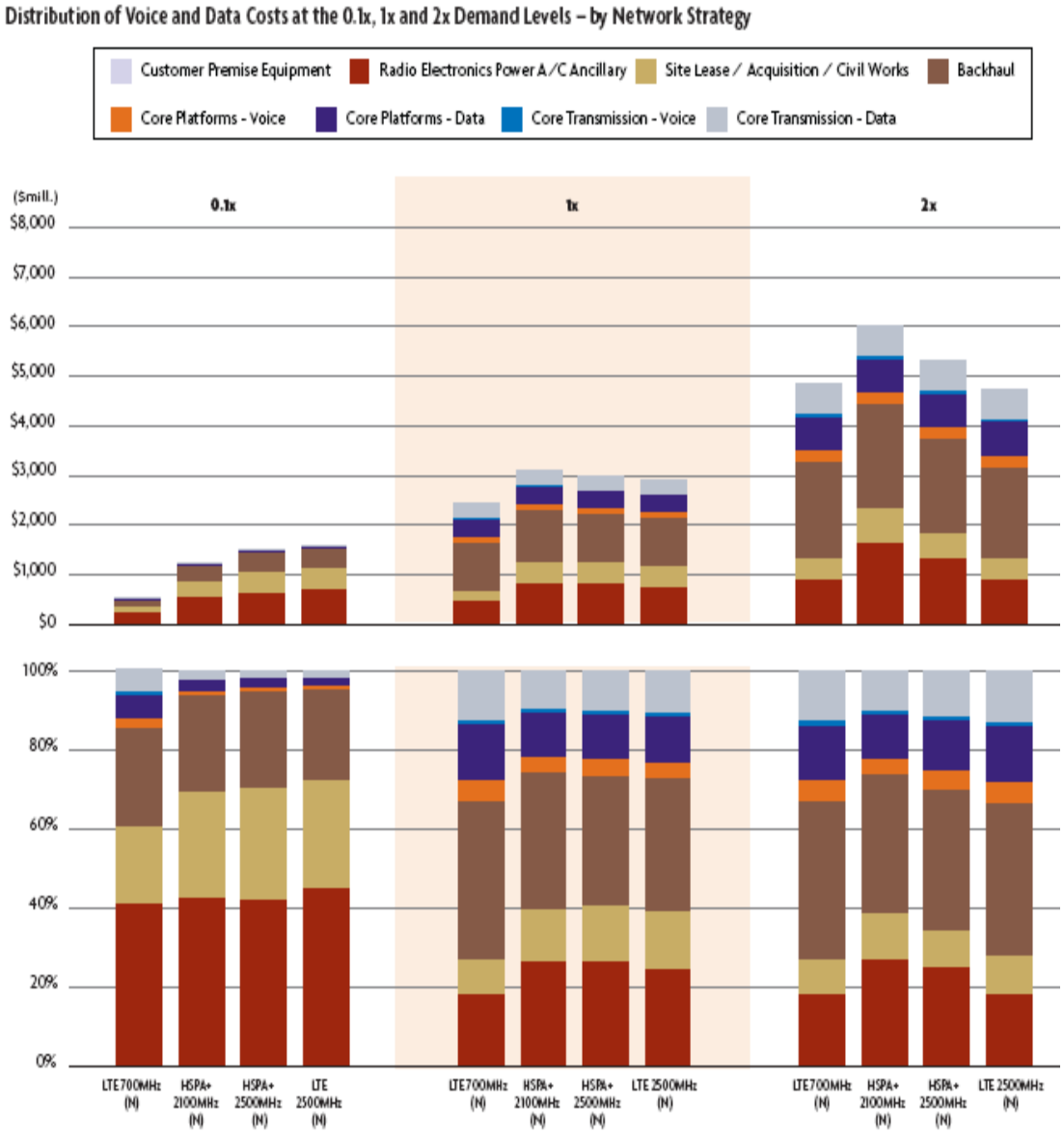
LTE Case Study – Results (Utilization and Site count) as a function of demand





- As utilization rates improve with increased demand the economics become more attractive.
- The merits of HSPA+ at 2100MHz start to become questionable with higher demand levels due to the number of capacity cell sites required.

LTE Case Study – Results (distribution of costs) as a function of demand



- At low demand levels the network economics are driven by the number of sites.
  - RAN Hardware
  - Site Lease, etc
- At higher demand levels the backhaul becomes the dominant cost driver.
  - The choice of backhaul is RAN neutral
- The core network related expenses are largely on par with the RAN-related expenses.

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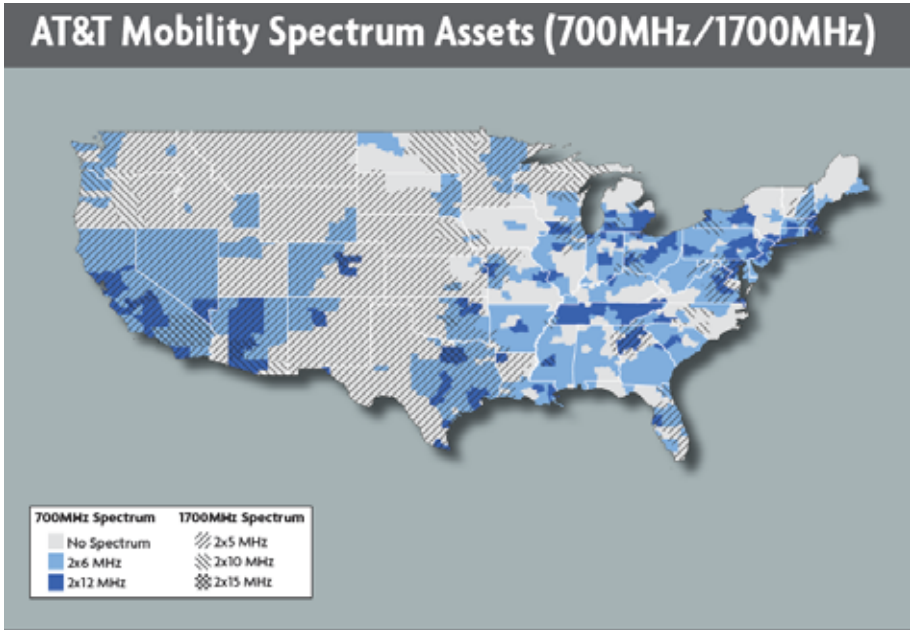
Auction 73: US Case Study

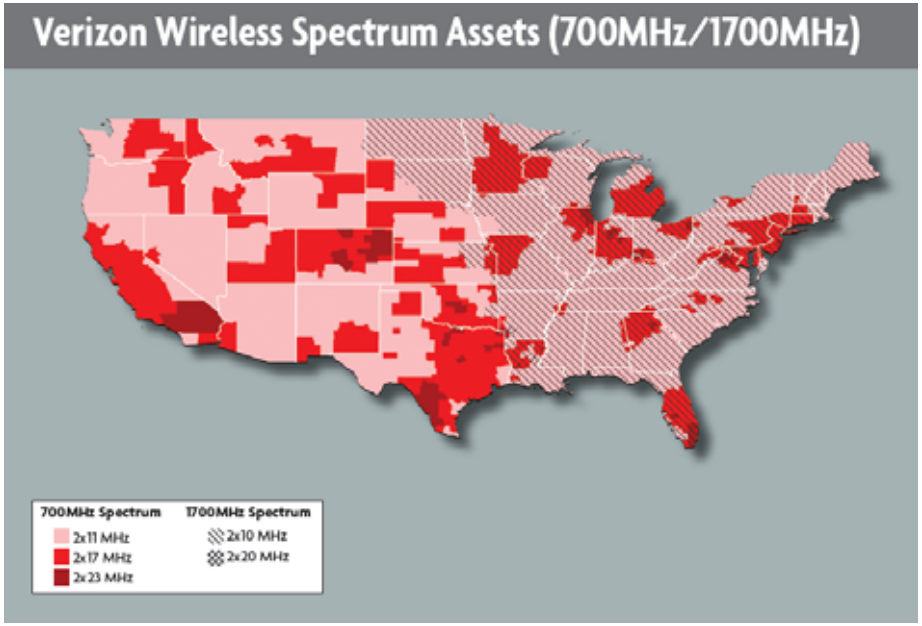
A Quick Look at LTE in North America

- Following Auction 66 and Auction 73, operators are poised to deploy their respective choice of technologies.
  - Most of the incumbent operators have confirmed an intent to deploy LTE
  - At the same time these operators haven't ruled out deploying HSPA or EV-DO

- Given the high expectations for LTE and/or 700MHz, there are a number of key questions that can be posed.
  - How do FCC buildout requirements for Auction 73 impact the operator's business case?
  - How does the cost of the licenses impact the economics?
  - How do the economics vary by licensed regions (e.g., at the CMA/EA level)?
  - How sensitive are the economics to the amount of traffic on the network(s)?

Major Operator Spectrum Positions for LTE





- Of the two big incumbent operators, Verizon Wireless has meaningful more 700/1700MHz than its biggest competitor.
- AT&T Mobility has spectrum from the merger/decommissioned TDMA network as well.
- T-Mobile USA will use 1900MHz for LTE after it gets subscribers onto its HSPA network at 1700MHz.
- SpectrumCo has 1700MHz spectrum that will probably be sold and used for LTE.

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Key Assumptions and Methodology Overview

- We selected an operator that was one of the bigger winners in Auction 73.
- We included the operator's total spectrum holdings (700/1700MHz) and amount paid for the spectrum by CMA/EA.
- We created "micro areas" which represent the resultant areas when CMAs and EAs are overlaid on top of each other.
- We modeled representative numbers for the cost and performance of a Greenfield LTE network with a flat IP core network and IP transport.
- We assumed the FCC network buildout requirements for 2019.
  - 70% geographic coverage by CMA/EA with various adjustments per the FCC requirements
  - Cost 231-Hata propagation models for coverage
  - Fully mobile network with 90% probability of achieving a 128kbps uplink transmission

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Key Assumptions and Methodology Overview (cont'd)

- We assumed three demand scenarios.

	Low Demand	Medium Demand	High Demand
Mobile Voice	1,500 minutes	1,500 minutes	1,500 minutes
Mobile Data	100MB	500MB	3GB
Fixed Data	5GB	15GB	50GB

- We assumed various penetration/adoption rates (e.g., wireless penetration rate = 90%).

- We "distributed" the usage between access technologies and between frequency bands. (amount of traffic on LTE is reduced due to wide availability of fiber, competition among LTE operators, and availability of other access technologies/frequency bands)

- These assumptions resulted in the following traffic per POP usage assumptions across all OFDMA networks.

(Traffic per POP)	Low Demand	Medium Demand	High Demand
Mobile Voice	203 minutes	203 minutes	203 minutes
Mobile Data	23MB	113MB	675MB
Fixed Data	170MB	509MB	1,696MB

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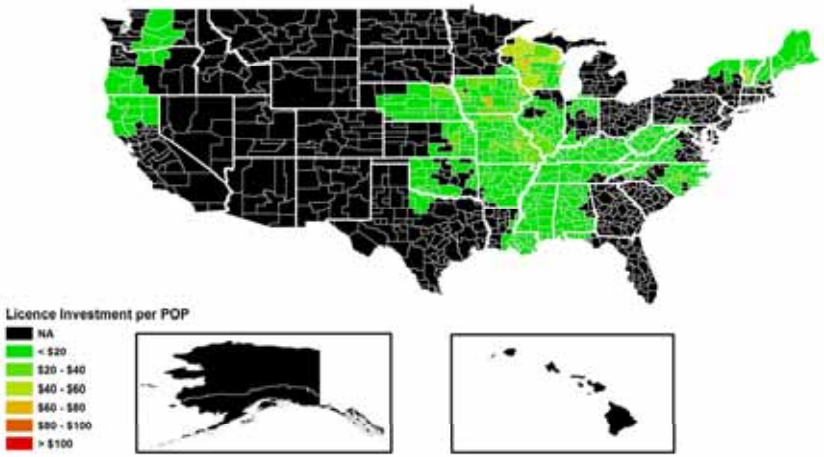
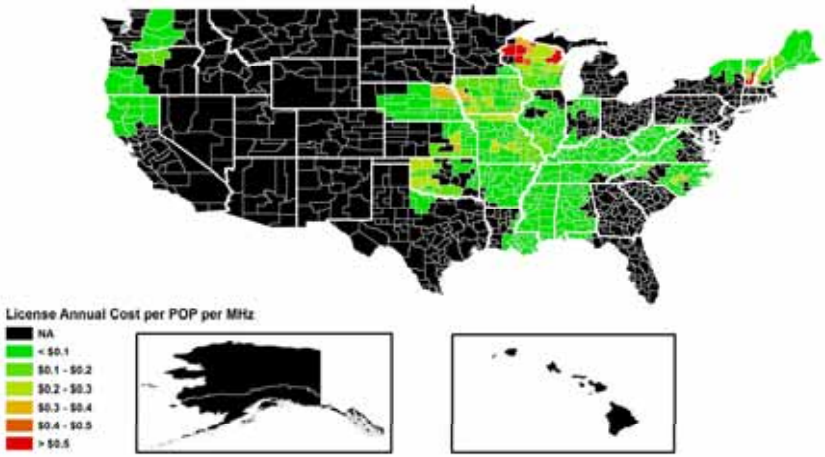
What an operator paid for its spectrum

Annual License Cost per POP



Annual License Cost per POP per MHz



- This operator spent on average $9.72 per POP ($0.57 per POP per MHz) for its spectrum.
- This equates to an annual allocated cost, which is a function of depreciation and the cost of capital, of $1.53 per POP and $0.09 per POP per MHz, respectively.
- The license cost per POP per MHz metric is more meaningful and it does a better job of indicating regions where the operator felt the spectrum was worth more on a per POP/MHz basis.

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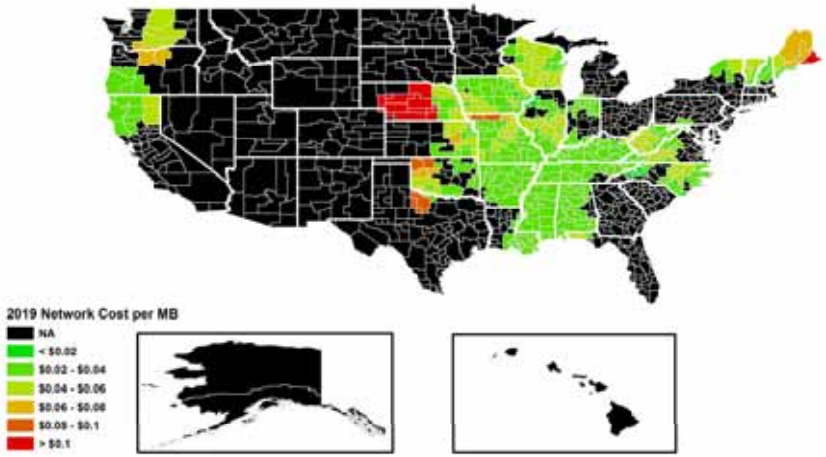
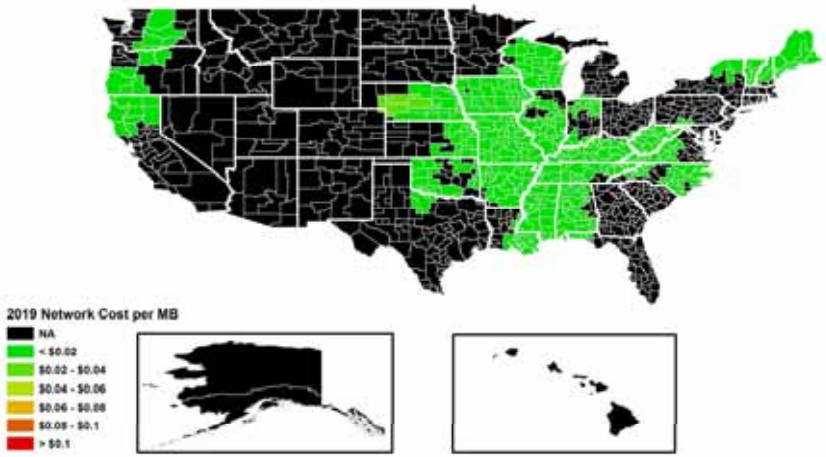
Network Cost per MB with 2019 FCC requirements (excludes license cost)

Low Traffic Assumption



High Traffic Assumption



- With low network traffic assumptions, the economics become more challenging in certain areas (largely rural).
- In these areas the operator could adopt a less aggressive strategy (e.g., nomadic coverage versus full mobility).
- With high network traffic assumptions the economics ($/MB) become more attractive in all areas.

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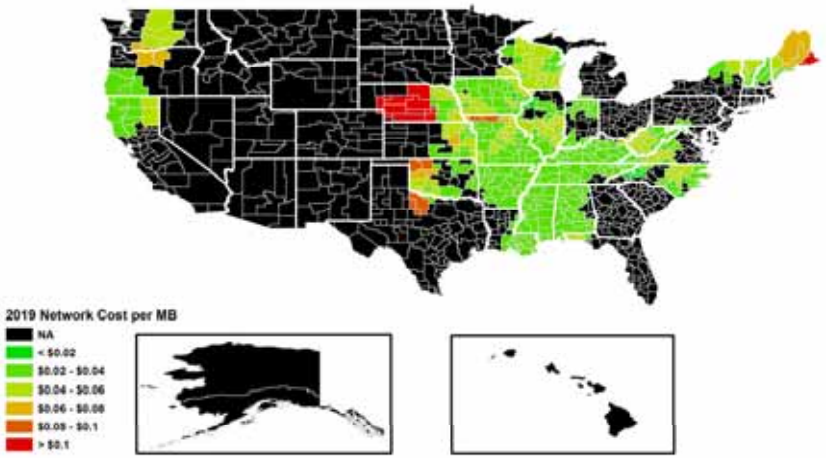
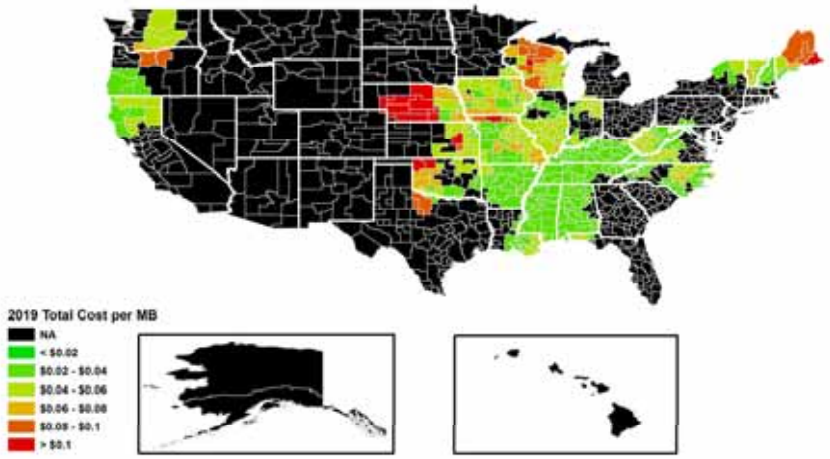
Evaluating the impact of license costs with the low demand scenario

Network Costs per MB
(excludes license costs)



Total Cost per MB
(includes license costs)



- License costs impact the economics in some regions more than other regions.
- Once license costs are included the economics become less favorable in certain regions.
  - Examples include areas of Wisconsin, Maine, Oregon/Washington, and Missouri
- The results of the high traffic scenario are less interesting and are not shown.

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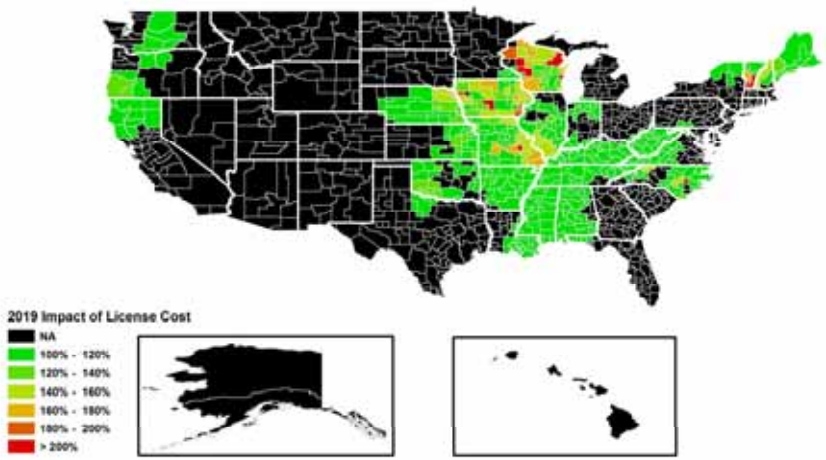
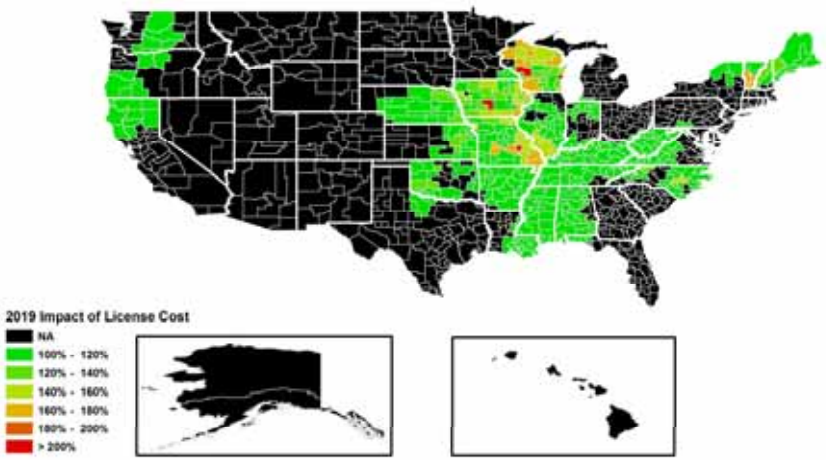
The impact of license costs with varying demand assumptions

Impact of License Cost
(Low Traffic Assumption)



Impact of License Cost
(High Traffic Assumption)



- The cost of the spectrum has a greater contribution to network economics in some regions than in others.
- With higher amounts of traffic the contribution from the spectrum costs is less meaningful.
- In most regions, network economics for a given amount of network traffic are driven by the cost of the network and not the cost of the spectrum.

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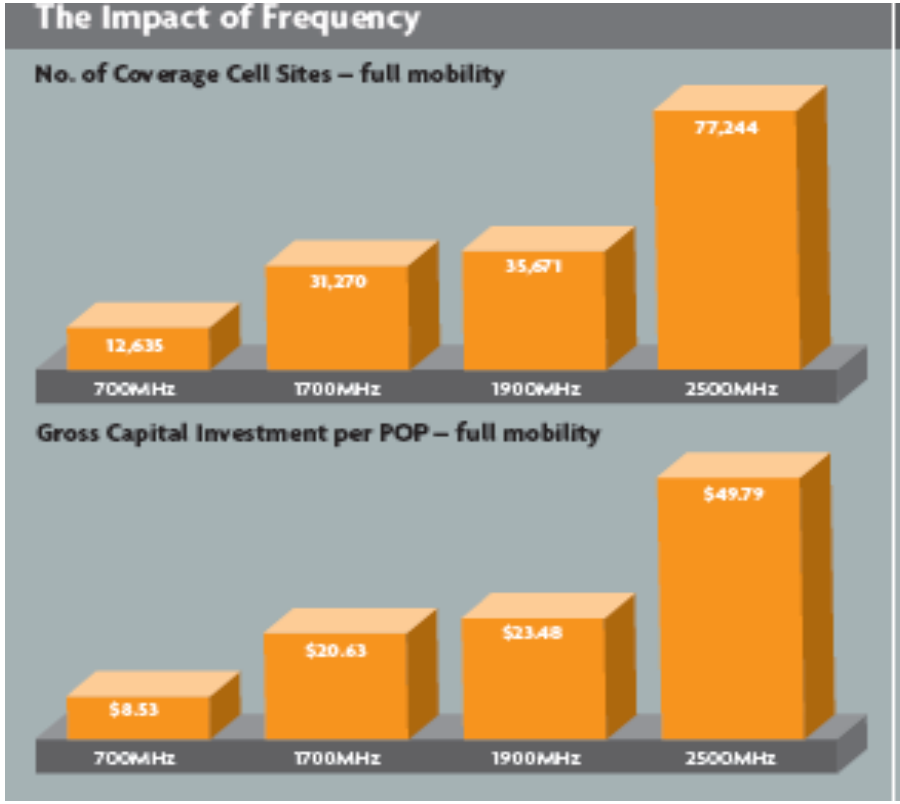
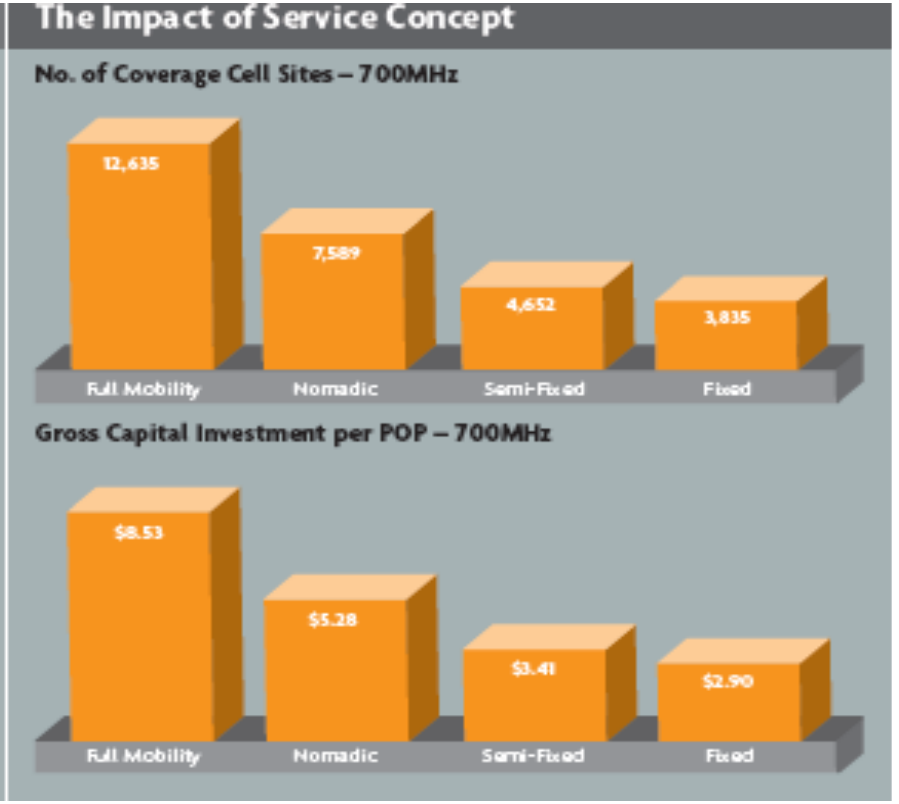
A sensitivity analysis on the impact of frequency and service concepts (analysis done for the B Block and 2019 FCC requirements)





- An operator deploying at 2500MHz (TDD) requires 6 times more cell sites to meet the FCC buildout requirements for 2019.

- By reducing the quality of coverage (e.g., nomadic versus mobile) an operator reduces its upfront investment.

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