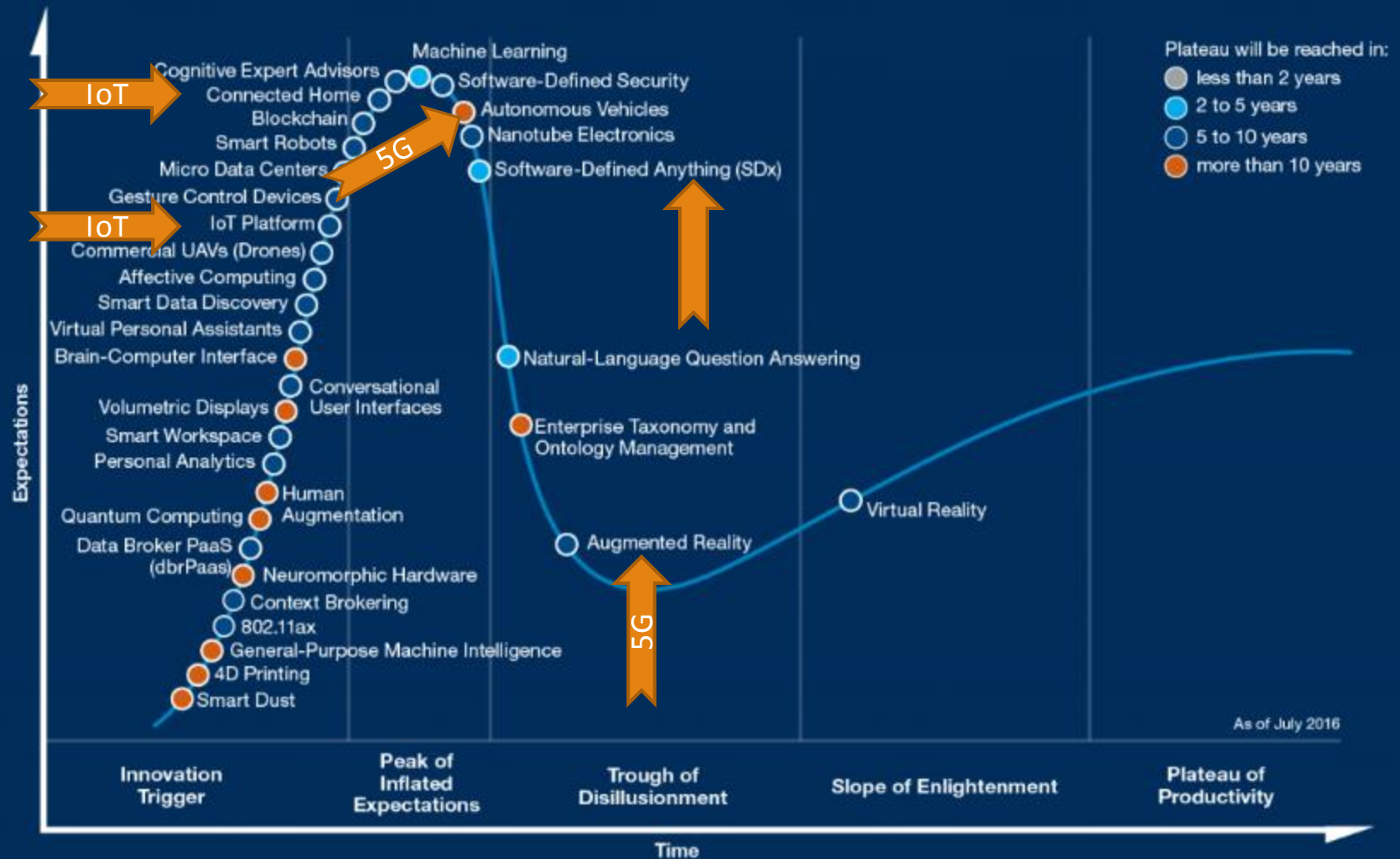


5G — *Separating Hype from Promise*

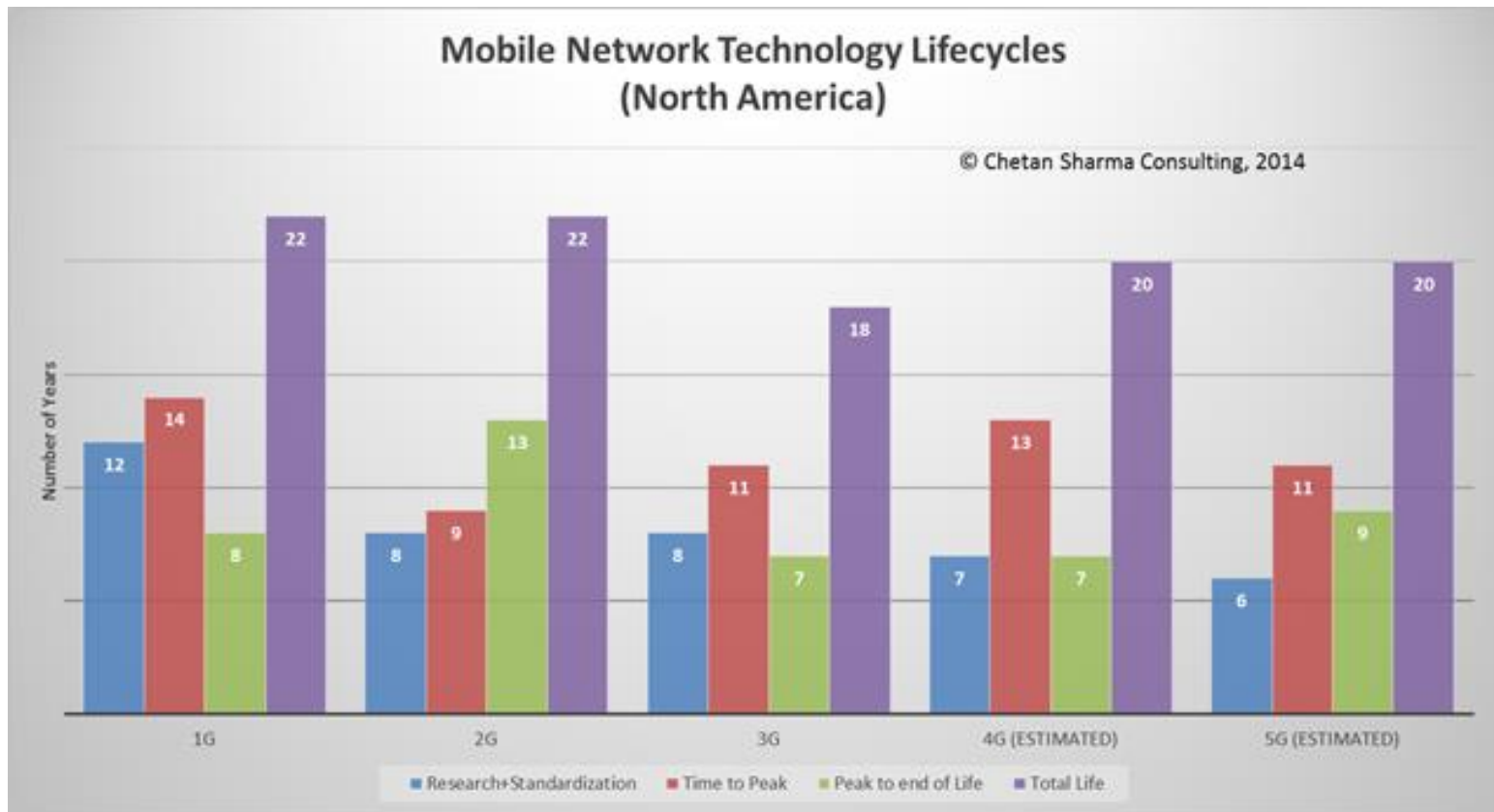
HENNING SCHULZRINNE

The views and opinions expressed in this presentation are those of the author and do not necessarily reflect the official policy or position of any agency of the U.S. government. Any resemblance to actual policies, living or dead, or actual events is purely coincidental.

Gartner Hype Cycle for Emerging Technologies, 2016

















Design for 20 years



Generations are distinct

Talking a different language

Formative experiences	Maturists (pre-1945) Wartime rationing Rock'n'roll Nuclear families Defined gender roles - particularly for women 	Baby boomers (1945-1960) Cold War 'Swinging Sixties' Moon landings Youth culture Woodstock Family-orientated 	Generation X (1961-1980) Fall of Berlin Wall Reagan/Gorbachev/ Thatcherism Live Aid Early mobile technology Divorce rate rises 	Generation Y (1981-1995) 9/11 terrorists attacks Social media Invasion of Iraq Reality TV Google Earth 	Generation Z (Born after 1995) Economic downturn Global warming Mobile devices Cloud computing Wiki-leaks 
Percentage in UK workforce	3%	33%	35%	29%	Employed in either part-time jobs or apprenticeships
Attitude toward career	Jobs for life 	Organisational - careers are defined by employees	"Portfolio" careers - loyal to profession, not to employer	Digital entrepreneurs - work "with" organisations	Multitaskers - will move seamlessly between organisations and "pop-up" businesses
Signature product	Automobile 	Television 	Personal computer 	Tablet/smartphone 	Google glass, 3-D printing
Communication media	Formal letter 	Telephone 	E-mail and text message 	Text or social media 	Hand-held communication devices
Preference when making financial decisions	Face-to-face meetings	Face-to-face ideally but increasingly will go online	Online - would prefer face-to-face if time permitting	Face-to-face	Solutions will be digitally crowd-sourced

land
line

2G

3G

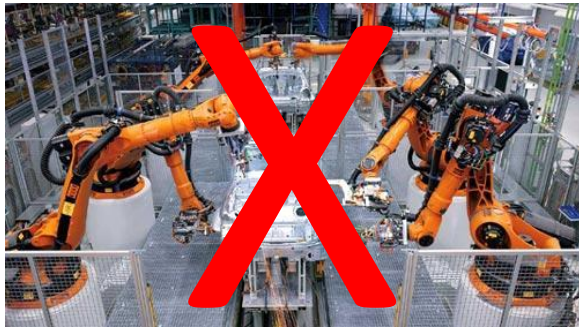
4G

Source: Barclays, University of Liverpool

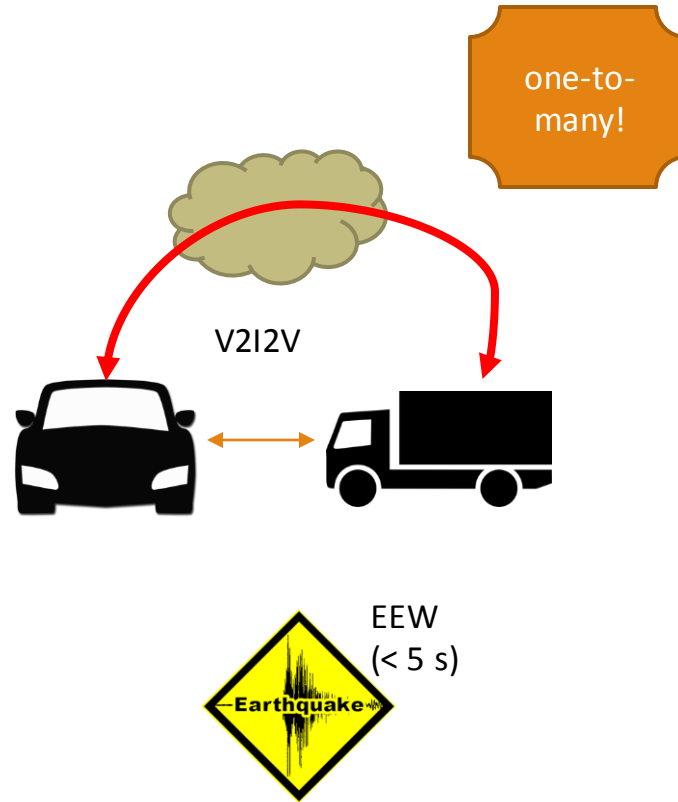
IoT requirements

Application	Range	Mo-bility	Device characteristics	Service characteristics	Suitable networks
<ul style="list-style-type: none"> • Connected car • Fleet management • Remote health monitoring 	~1000m	Yes	Rechargeable battery	Managed service, highly secure	<ul style="list-style-type: none"> • Cellular • Satellite
<ul style="list-style-type: none"> • Smart metering • Parking meter 	~1000m	No	Low rate, low power, low cost	Managed service	<ul style="list-style-type: none"> • Cellular • Dedicated network
<ul style="list-style-type: none"> • Hospital asset tracking • Warehouse logistics 	~100m	Yes	Low rate, low power, low cost	Enterprise-deployed	<ul style="list-style-type: none"> • WiFi • RFID
<ul style="list-style-type: none"> • Industrial automation • Home automation 	~10m	No	Low rate, low power, low cost	Subscription-free	<ul style="list-style-type: none"> • Zwave • Zigbee • Wifi • Powerline
<ul style="list-style-type: none"> • Personal activity • Local object tracking • Point of sale 	~1m	No	Low rate, low power, low cost	Subscription-free	<ul style="list-style-type: none"> • Bluetooth • NFC

5G low latency



LAN



tight control loop → near-100% availability

Niche networks persist



short range



ZigBee[®]

low energy;
mesh

tries to
usurp niche



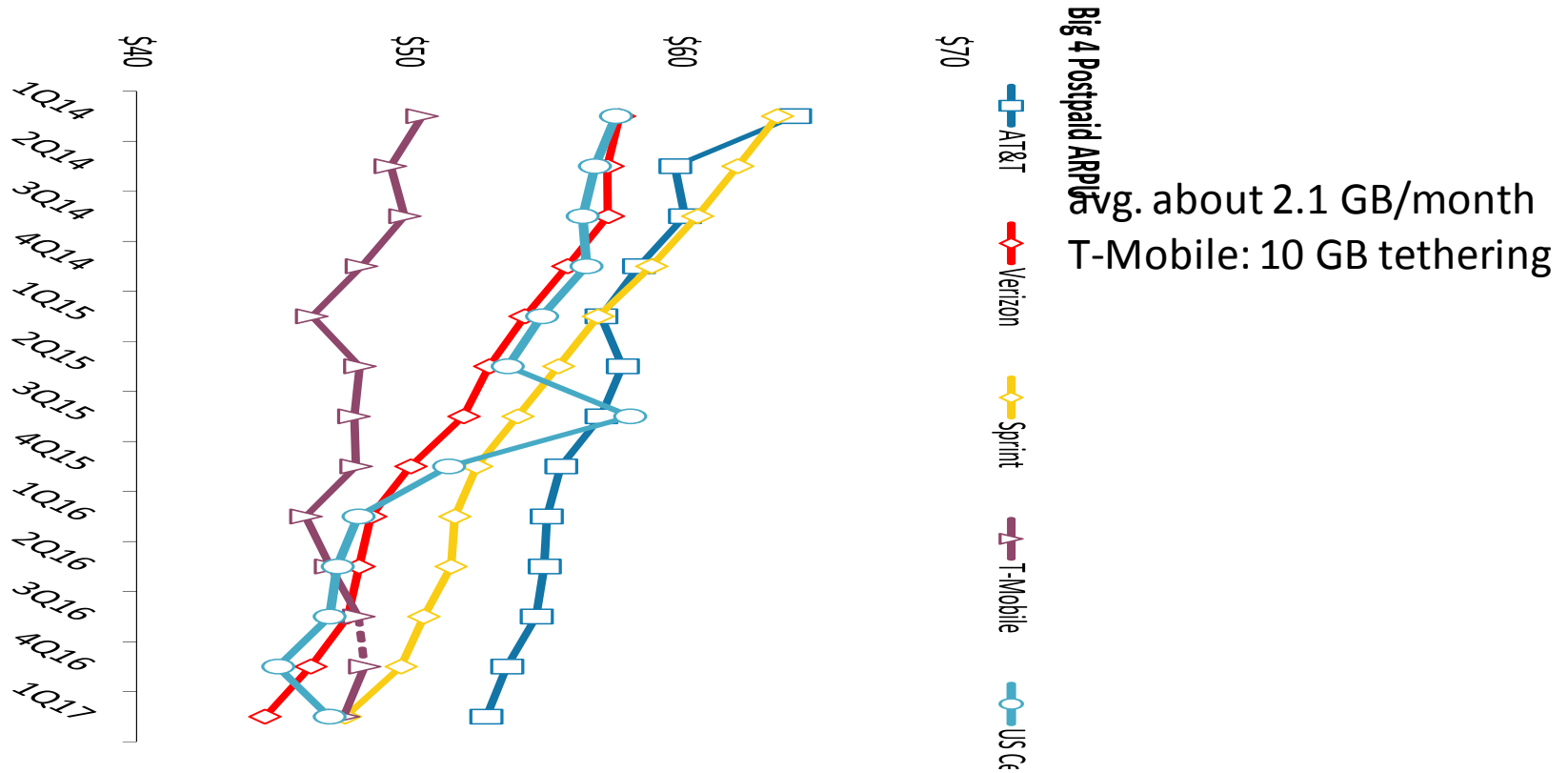
Bluetooth[®]

ubiquity; low
cost



speed; public
APs

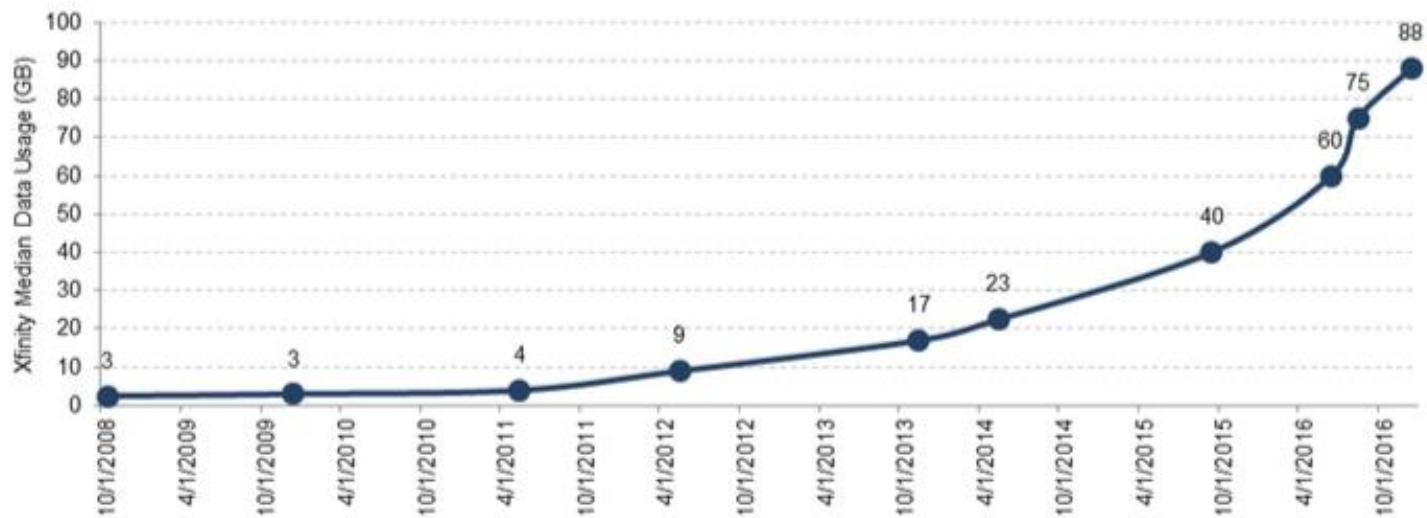
What's the economic case for 5G?



Cord-cutting for broadband?

Exhibit 13

Comcast: Median Bandwidth Usage per Household per Month, 2008 to 2016



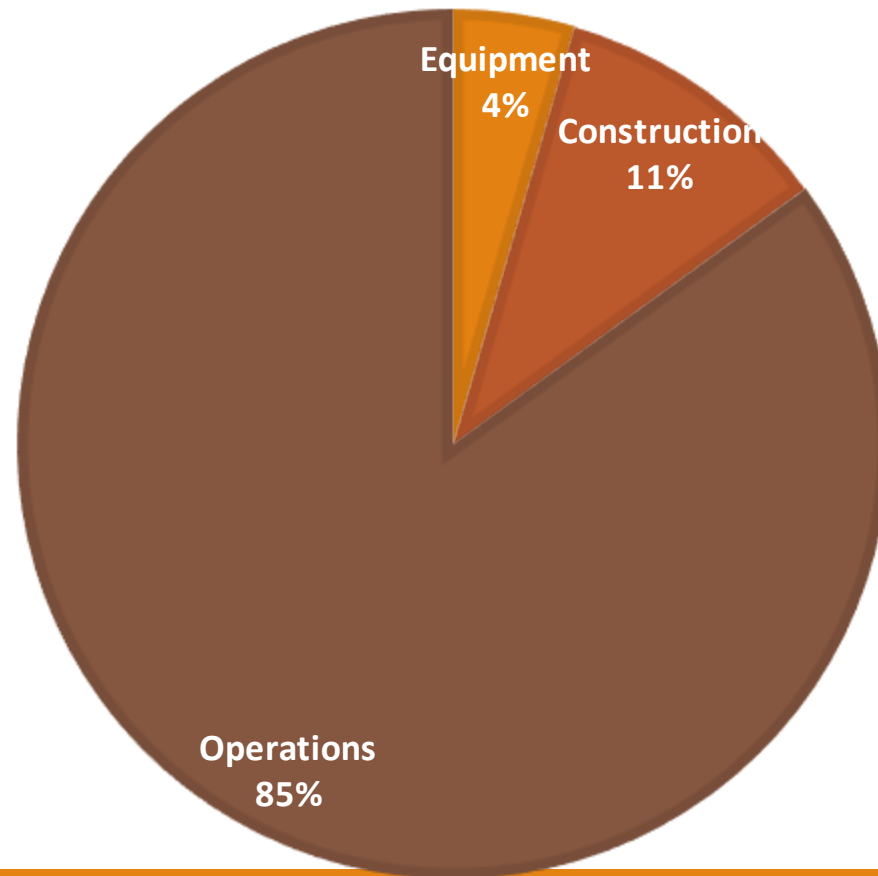
Source: Comcast's website, MoffettNathanson estimates and analysis

Network economics, (over)simplified

% OF REVENUE



■ Equipment ■ Construction ■ Operations ■



How can 5G be cheaper by GB?

Backhaul is major cost factor

- “Backhaul costs represent almost 6% ... of a wireless carrier total operating expenses (OPEX) and 30% of total network costs.”

Re-use existing fiber to residential users

- Requires cooperation of cable/FTTH provider

Reduce license cost for spectrum → unlicensed, mmWave

- first step: LTE-U

Table 5. Wireless Network Cost Breakdown (OPEX and Headcount CAPEX)

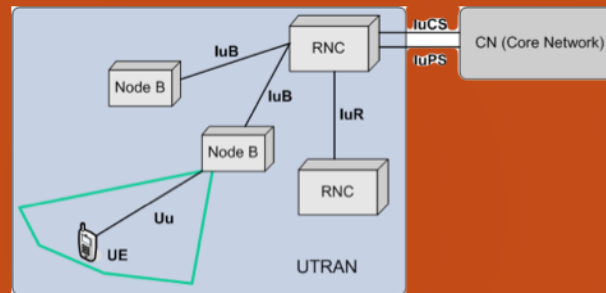
Subcomponents	Carrier A	Carrier B	Carrier C	Carrier D	Average of All Carriers
Strategy and Support	13	8	10	19	14%
Network infrastructure rent	36	45	33	37	39%
Transmission	6	5	13	8	7%
Core Network	10	9	13	3	8%
Radio ops & maintenance	11	15	18	14	14 %
Radio deployment	13	8	8	10	10 %
Radio design	10	9	5	8	8 %

Source: *Wireless Carriers Benchmarking Study*

Network architecture

Networks 1G through 4Gish

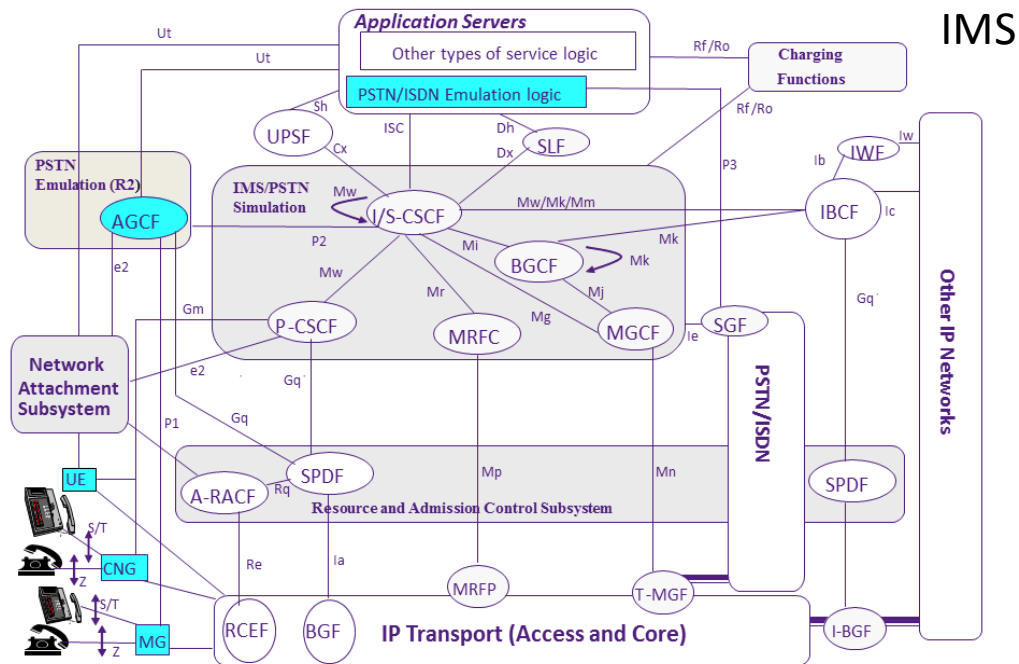
national carrier



*one subscriber,
one phone,
one provider*



Complexity kills



IMS /VoLTE

IMS = It Mostly Speaks
VoLTE = Voice-Only Later than Expected

VoLTE: Taking Carriers Beyond Voice

🕒 Mon, 06/06/2011 - 12:43pm

👤 by Maisie Ramsay

✉ [Get today's wireless headlines and news - Sign up now!](#)

Project yourself into the future – let's say mid-2012. It's been about a year and a half since Verizon Wireless first launched its LTE network in December 2010, and after a long wait, the company has finally come out with the first smartphone running voice over LTE (VoLTE) technology.

You go out and buy the device, turning it on the second you have it out of the box. One of the first things you notice: The phone's native voice application isn't limited to just voice. It has an option for video calls, and there's also an option to send multimedia messages, along with presence indicators that show when people on your contact list can participate in a video call.

AT&T, Verizon Target VoLTE Interop in 2015, RCS Later

By Doug Mohny / November 04, 2014

AT&T and Verizon have officially declared they are working on Voice over LTE (VoLTE) connections between their respective networks and customers. VoLTE calls between Verizon and AT&T customers "is expected" in 2015, according to a statement from the companies. And, there's also some Rich Communications Services (RCS) news buried in the text.



The announcement comes as three out of four major U.S. carriers promote LTE networks and a number of countries plan to turn up LTE and VoLTE in the next 15 months. "Interoperability among VoLTE service providers in the United States and around the world will create a better and richer mobile experience for customers," declares Verizon's press release.

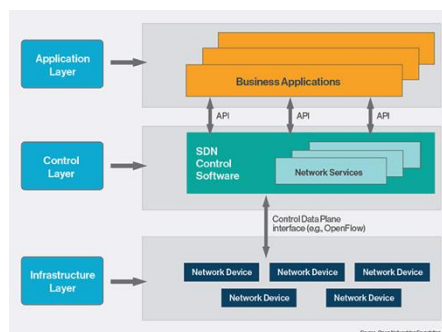
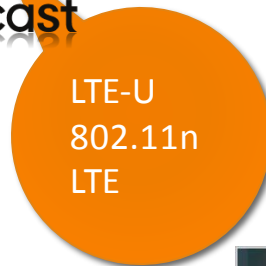
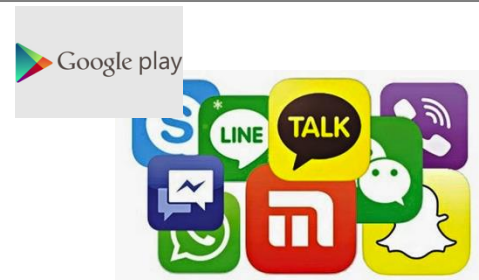
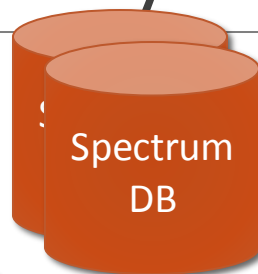
Vodafone Germany announces VoLTE rollout

17 Mar 2015

🇩🇪 Germany

Vodafone Germany claims it has become the first German operator to initiate the rollout of voice-over-LTE (VoLTE), having demonstrated the first live VoLTE call on its network at the CeBIT 2015 technology fair in Hanover. The UK-owned operator says that the technology offers customers an 'unprecedented voice service and telephony experience', ensuring 'crystal clear voice quality, super-fast call set-up and encrypted phone calls' across its LTE network, which currently covers 70% of Germany. Vodafone revealed that it will soon be launching new LTE smartphones for VoLTE, including handsets from manufacturers such as Samsung, Sony and HTC. The announcement follows reports last week that Vodafone plans to introduce both Wi-Fi calling and VoLTE in the UK this summer, following trials of the technologies in laboratory conditions.

5G – what exactly is a carrier?

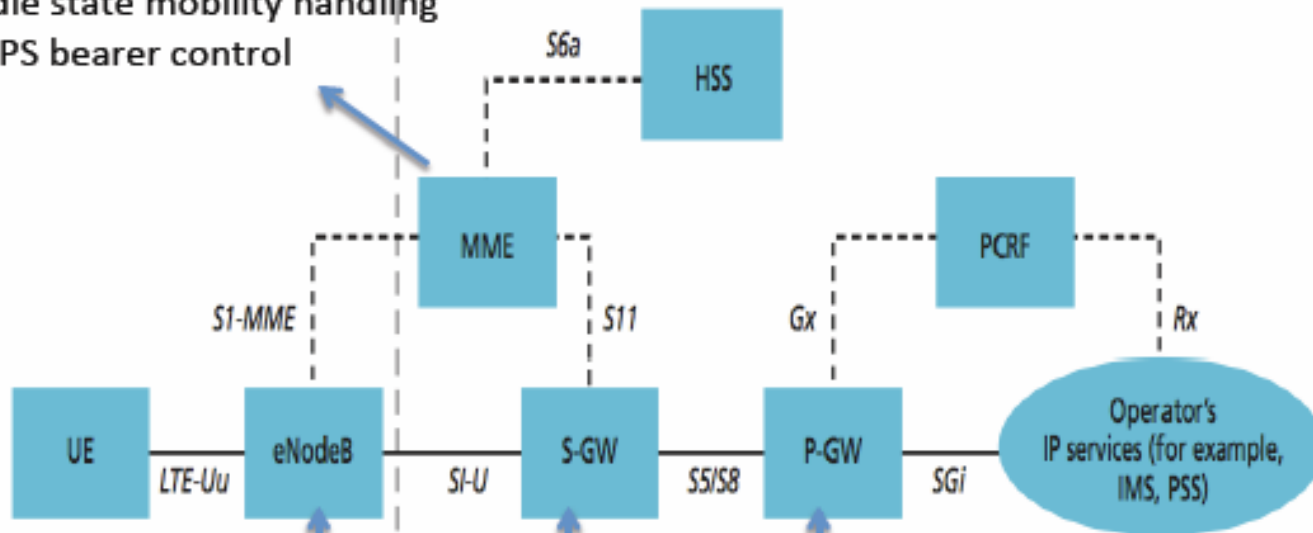


LTE – one carrier, plus roaming

NAS security

Idle state mobility handling

EPS bearer control



Radio bearer control

Inter-cell RRM

Connection mobility Control

Radio admission control

Mobility anchoring

UE IP address allocation
Packet filtering

5G: Carriers as consumer brand

Outside



Inside

Network Managed Services



Through Network Managed Services, we can take full responsibility for your network, including planning, design and implementation, day-to-day operations and maintenance.

Service description

The Network Managed Services offerings include all activities we would typically perform running a telecom network, for instance:

- Day-to-day operation and management of the entire network infrastructure
- Management of end-customer problems escalated from your customer care function



What are carriers good at?

Research?

Software development?

- Who is going to develop those 5G SDN applications?

OTT applications?

API-based services?

- Why did Twilio and Tropo offer voice service APIs and not the ILECs?

The law of new networks

“Any new network technology will be justified on (finally) providing QoS”

To succeed, they have to provide good-enough QoS for best effort

- at least with competition

The business model for QoS is difficult

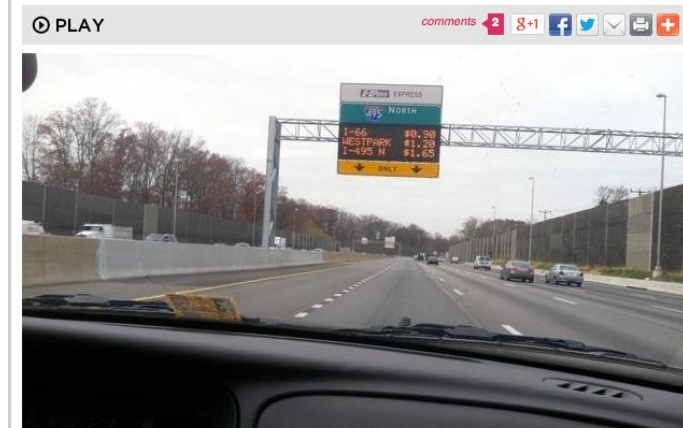
- see bypass toll roads

QoS is usually not accessible to applications

- or not end-to-end

I-495 Express Lanes Endure Big Losses Early On Way To Potential Profit

By: Martin Di Caro
February 20, 2015



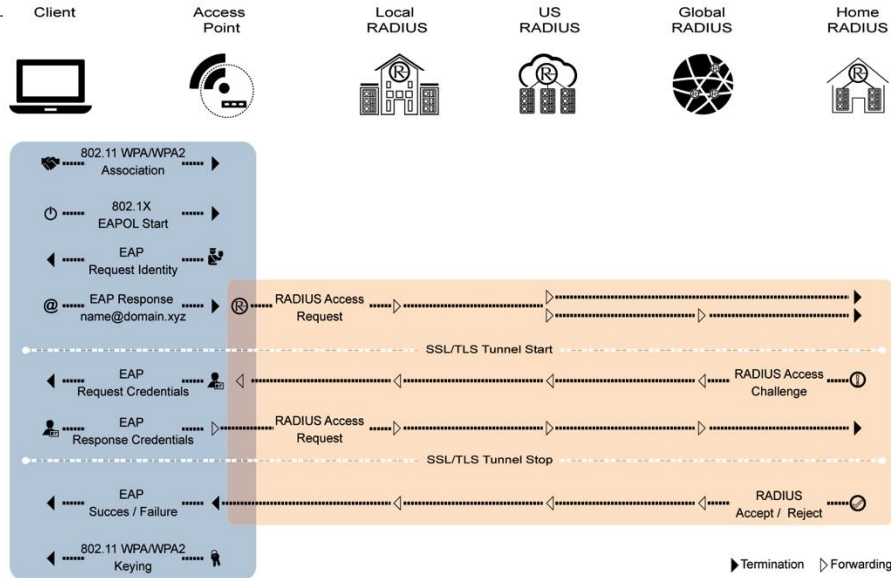
WAMU/Martin Di Caro

The 495 Express Lanes offer a paid respite from the usual Beltway traffic, but fewer drivers than expected are using them.

The private sector firm that operates the 495 Express Lanes along the Beltway in Northern Virginia is down more than \$230 million on its investment in the two and a half years since the highway opened, but company officials say toll revenues are beginning to consistently exceed operating costs, a sign the project is winning over commuters in one of the region's most congested corridors.

Transurban, the Australia-based toll road builder that operates high-speed HOT (high-occupancy toll) lanes on I-495 and I-95, has said all along it would take years to turn a profit on its enormous investments in Northern Virginia.

5G prototype: Eduroam



Brian, a LSU Student, is visiting University of Tennessee and joins eduroam



Brian has secure, seamless, and instant WiFi



Brian's credentials (brian@lsu.edu) are securely sent to eduroam



UTK grants Brian network access



eduroam routes the information to LSU



eduroam routes the information to UTK



Brian's credentials are verified by LSU



LSU confirms Brian's credentials to UTK



5G opportunities beyond hype

Applications surprise

Low cost per GB carried (capex & opex) may beat QoS

- fixed wireless and predictable motion (trains!) may be initial opportunity

Complexity kills

- layering (1984) and information hiding is still a good engineering principle

5G: 4G++ or opportunity for re-thinking design assumptions

- complexity vs. modularity