Wireless Communications Technologies and Research Trends:
Long Term Evolution –Advanced (LTE-A) and Beyond

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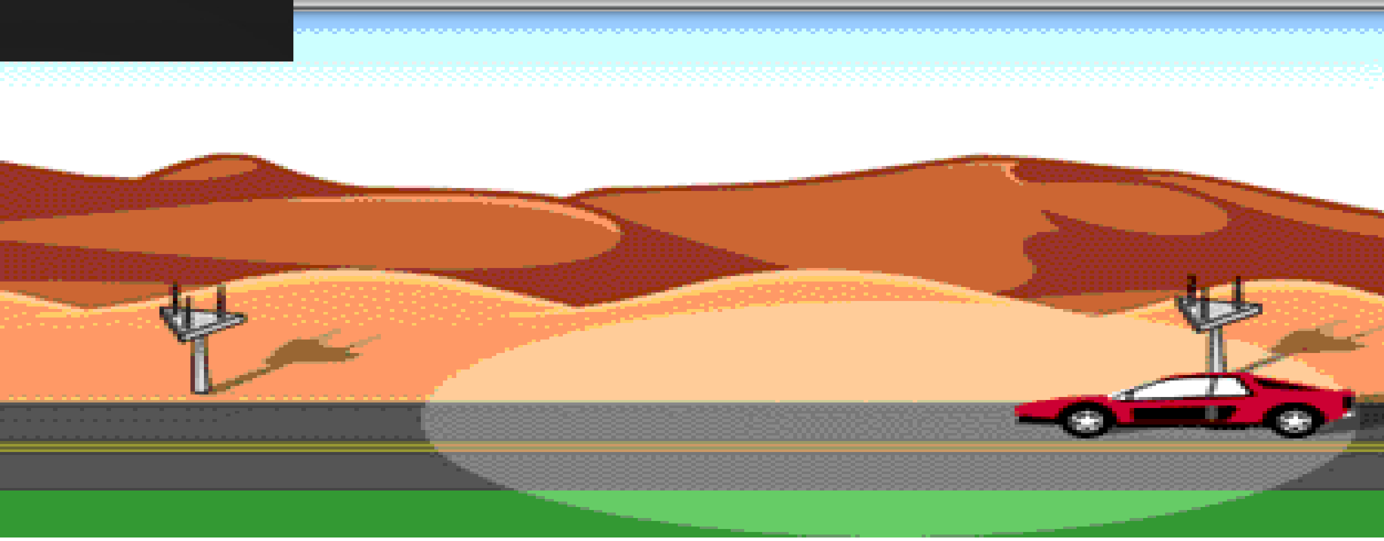
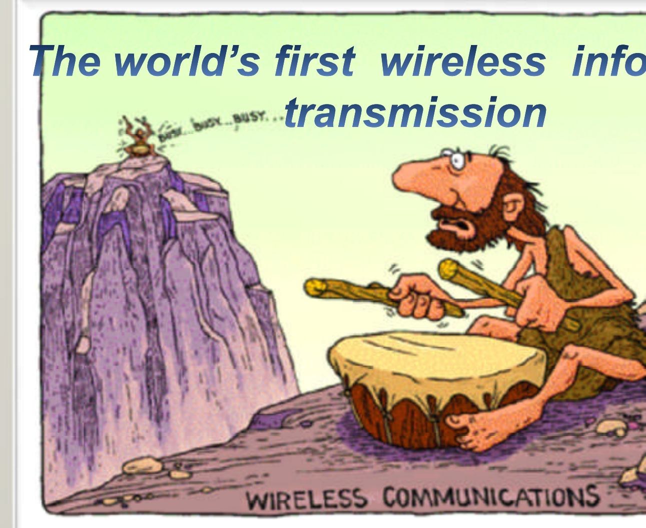
Murray State University, KY, USA





Wireless Communications Technologies and Research Trends: LTE-A and Beyond

4G or Not 4G?

Telecommunication Evolution and Trends

BC era, Cellular and mobile evolution pathways challenges

LTE and Emerging technologies for LTE –Advanced

OFDM & various MIMO enhancement

Channel/carrier aggregation

RN (Multi-hop Transmission)

CoMP (Multi-cell cooperation Tx/Rx)

Densification (small cell solution)

Interference management in heterogeneous cell overly (femtocll,wifi,..)

Challenges of LTE and LTE-A

5G : "several hundred times faster" than LTE or another Hype

Conclusion

or not 4G? That is the question

argument over what qualifies as real fourth-generation wireless technology and what is mere n upgraded 3G service hit a boiling point in December 2010 amid widespread marketing of iMAX, LTE and HSPA+ as "4G" service. The issue prompted the ITU the release a stateme hat seemed to concede that 4G had become more of a marketing term instead of a technical pecification.

the most advanced technologies currently defined for global wireless mobile broadband ommunications, IMT-Advanced is considered as '4G,' although it is recognized that this term, wi ndefined, may also be applied to the forerunners of these technologies, LTE and WiMAX, and t ther evolved 3G technologies providing a substantial level of improvement in performance and apabilities with respect to the initial third generation systems now deployed," the standards body aid.

T, Verizon Wireless and Sprint have all voiced their intentions to deploy LTE-Advanced, and learwire says the TD-LTE overlay for its WiMAX network will be "LTE-Advanced-ready." hey're all currently marketing their respective LTE and WiMAX services as 4G, and T-Mobi SA advertises its HSPA+ service as 4G.

Telecom Facts:

billion personal computers

billion fixed landline phones

2 billion TV sets

billion credit cards

d 1.1 billion cars

Everything goes mobile

Everything goes digital

Broadband goes wireless

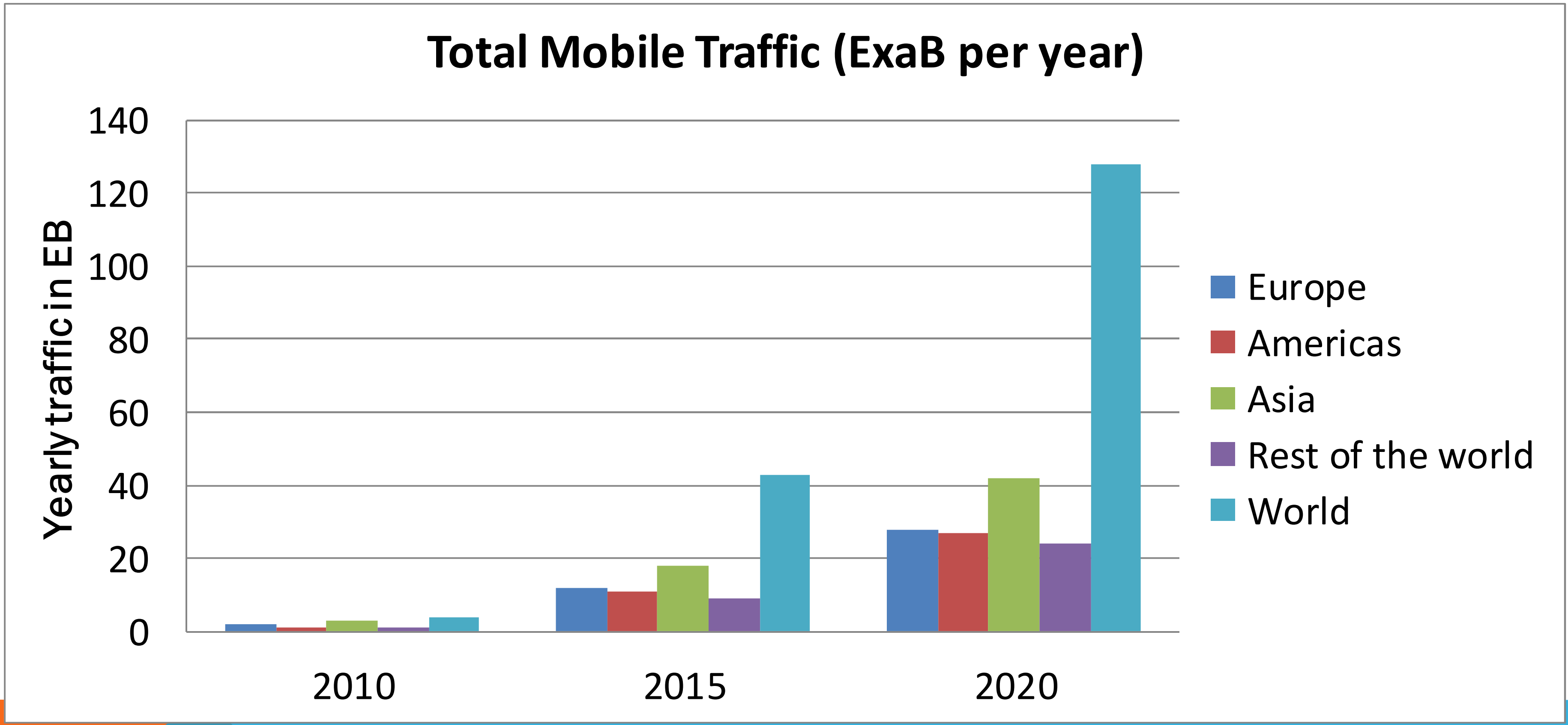
World population :
4 births per second

Mobile phones :
25 sold per second

w many mobile phones in use today?

- *In use today, yes,* *6.5B*   Six *times as many mobile phones as automobiles and more than five times as many as personal computers. About five times as many mobile phone owners as those of fixed landline phones or credit cards. And more than four times as many mobile phones in use as TV sets*

he resulting capacity Demand Prediction:



e than 127 Exabyte (10^18 byte)= More than 33 fold increase compare 010

Questions emerge on LTE

- How do commercial LTE networks perform in the “real world”?
- What are the LTE commercial deployments scheduled by Tier1 operators?
- Could LTE accelerate the consolidation of the mobile market?
- What is the cost of deploying LTE?
- Which type of operator benefits the most?
- Will LTE accelerate changes in pricing plans for mobile data?
- What are the regulatory constraints for LTE deployment?
- How many and what type of LTE devices will be rolled out this year?

CHANGING COMMUNICATIONS LANDSCAPE: TELECOM EVOLUTION

nterprise-Driven	Consumer-Driven
ardware-Centric	Software-Centric
ireline	Wireless
eople to Machines	Machine to Machine
eripheral Security	Embedded
roprietary Interfaces	Open (incl. Policy)

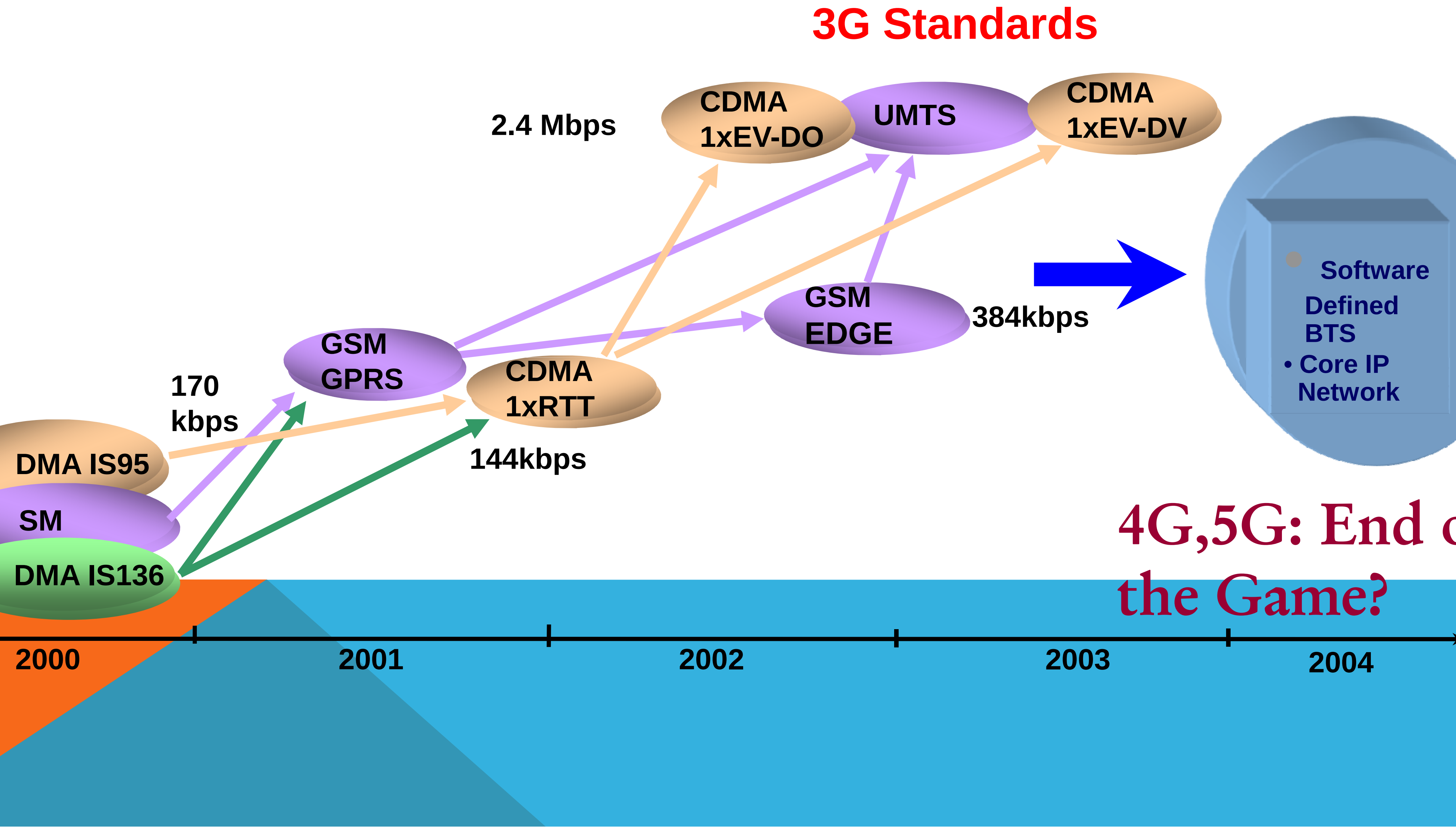
Everything On Line, Global, Horizontal, Open and wireless

STANDARDS EVOLUTION

ational & Regiona	Global
ompeting Organiza...	Collaborating
...tically Integrated	**Horizontal, Open Source**
ng Development Time	Short Development Time
ew forum per technology	Merged / Integrated
ch-Specific Spectrum	Tech & Service Neutral Spectrum

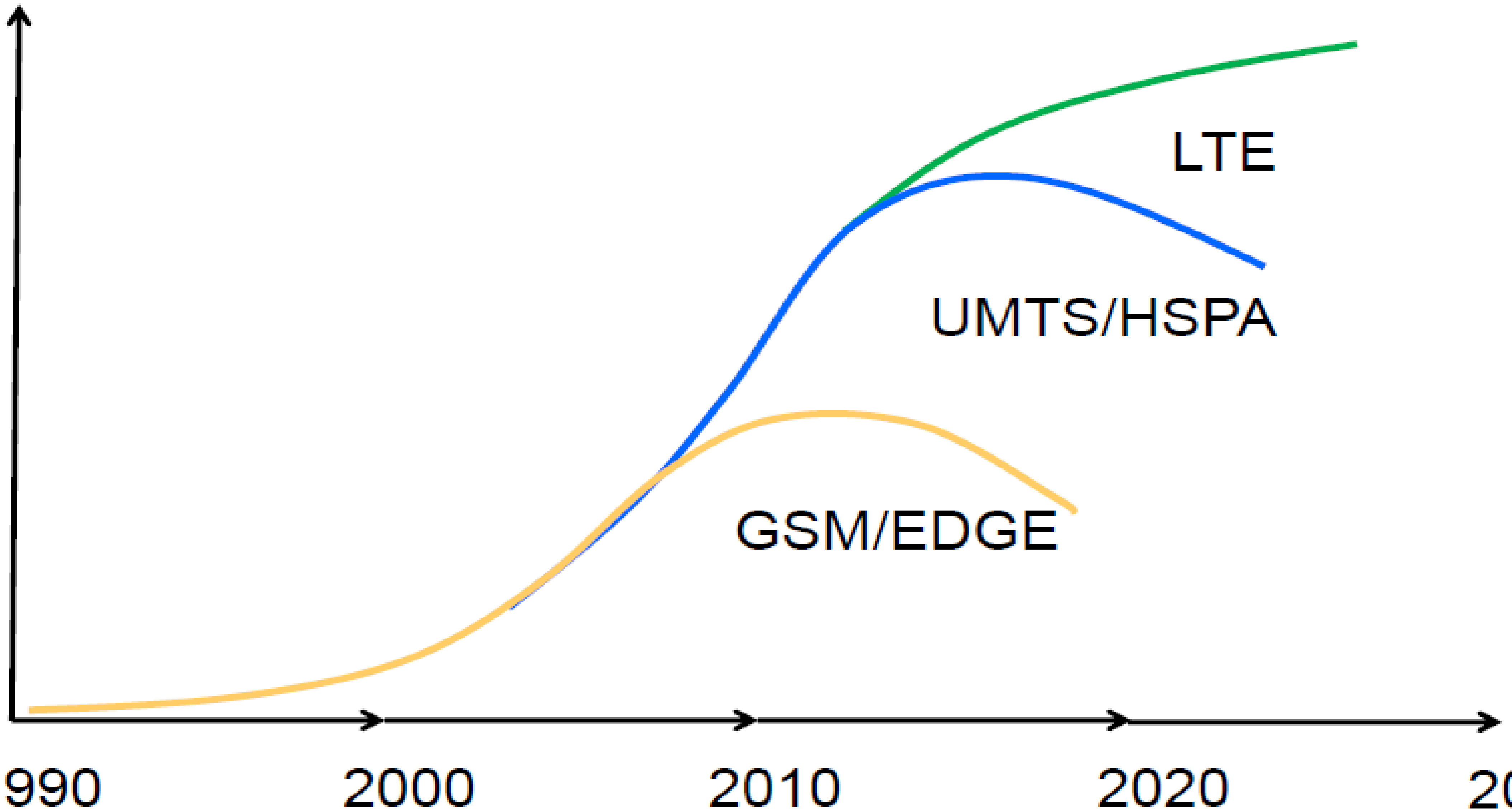
change is the only constant in communication field

OPERATOR EVOLUTION OPTIONS

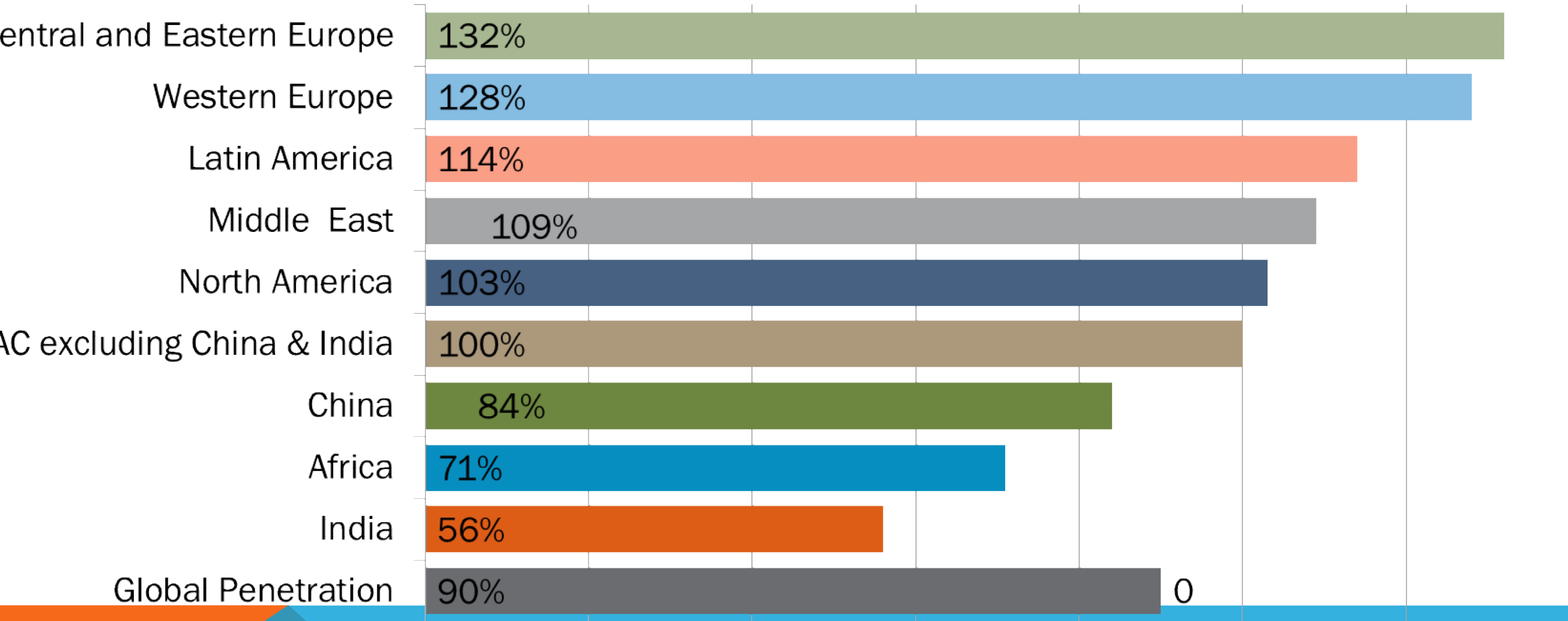


4G,5G: End of the Game?

RELATIVE ADOPTION OF TECHNOLOGIES



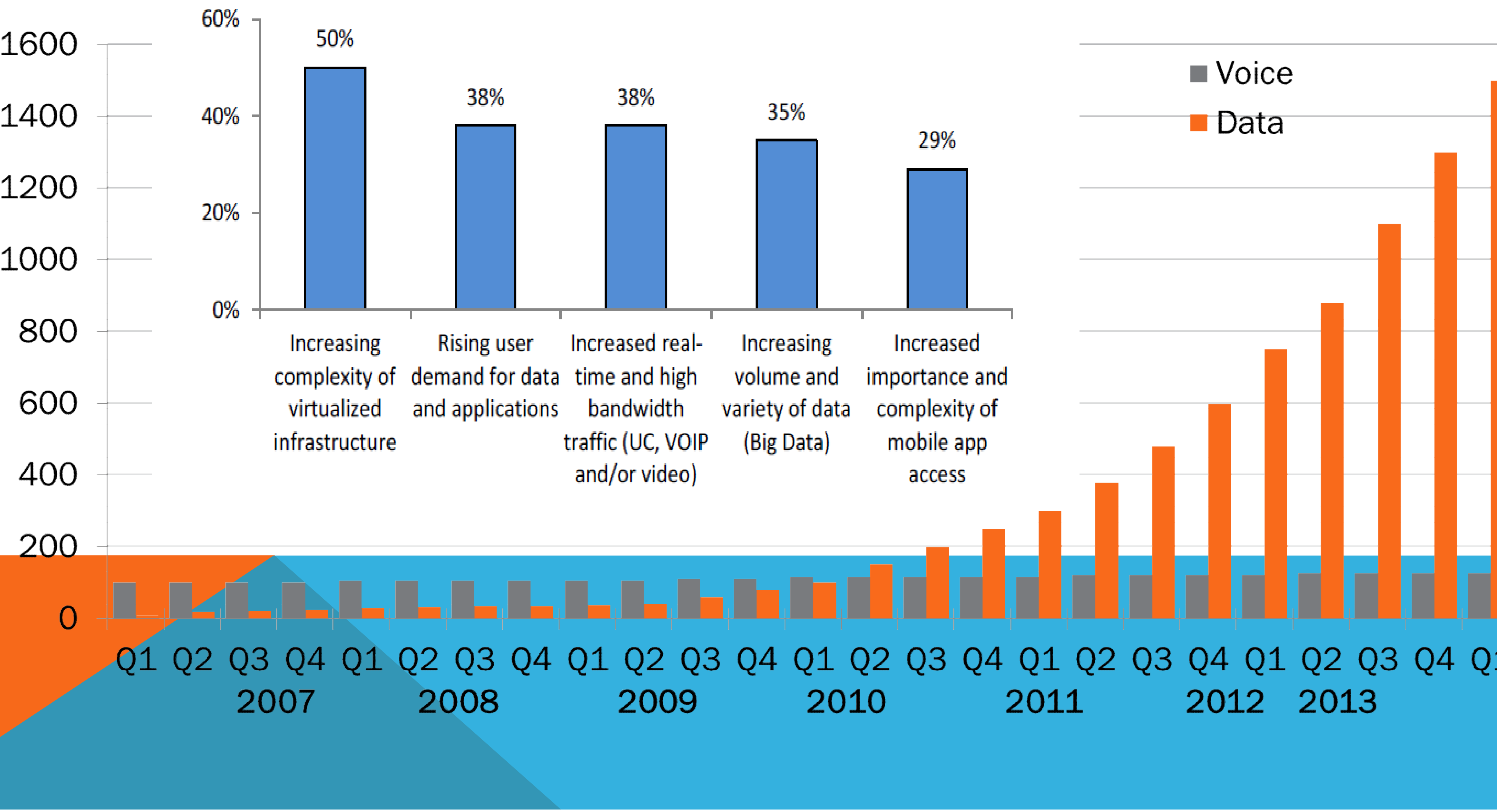
Penetration percentage, Q1 2013



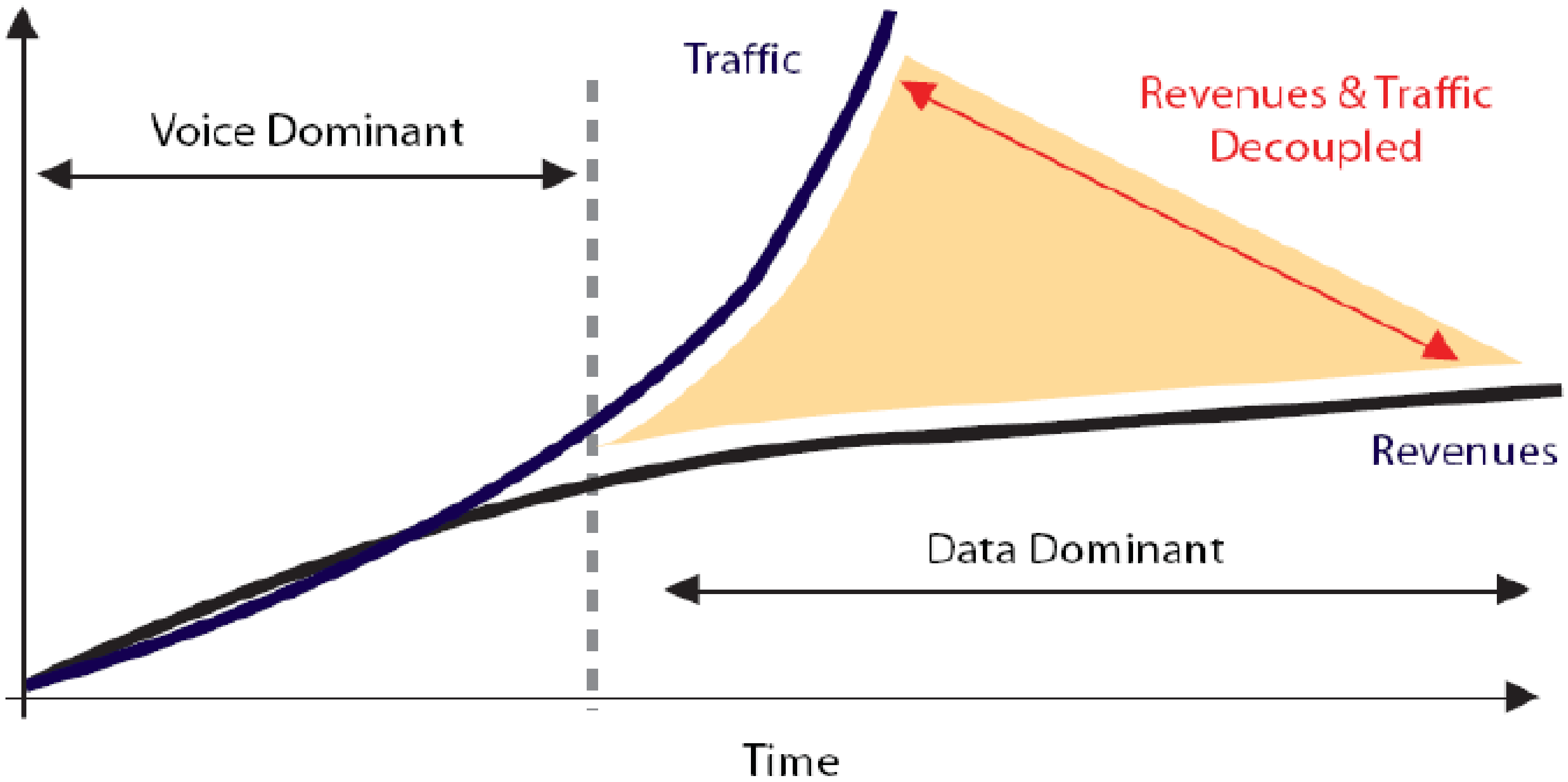
orld population : births per second

Mobile phones : 25 sold per second

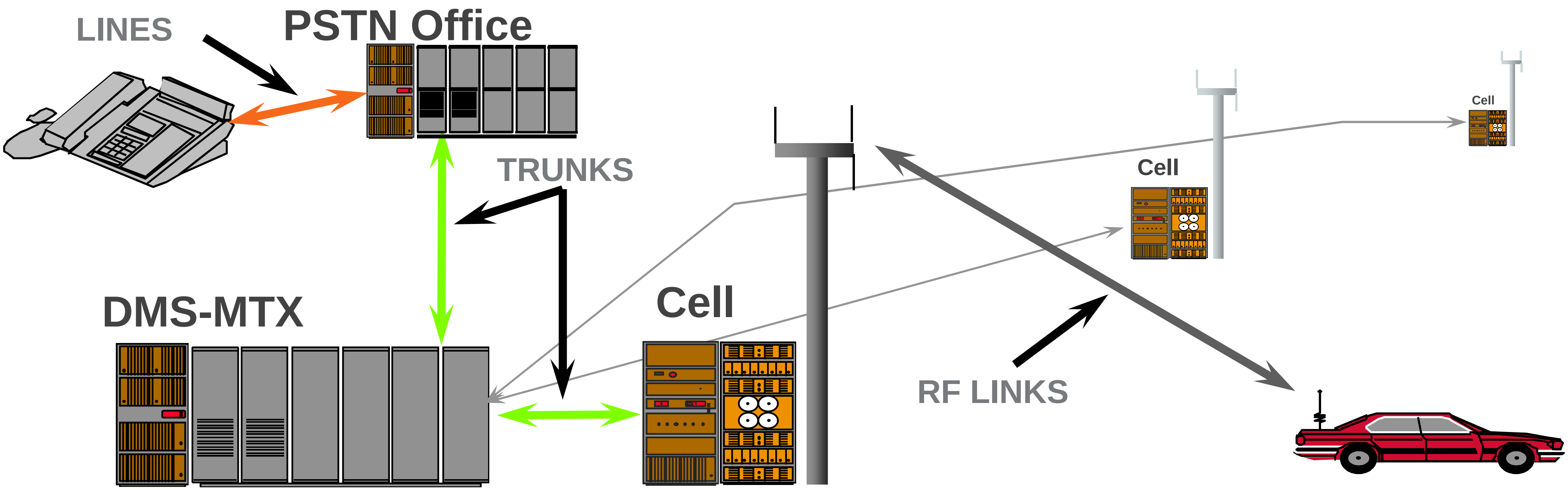
Global total traffic in mobile networks



Complete Decoupling between traffic and income

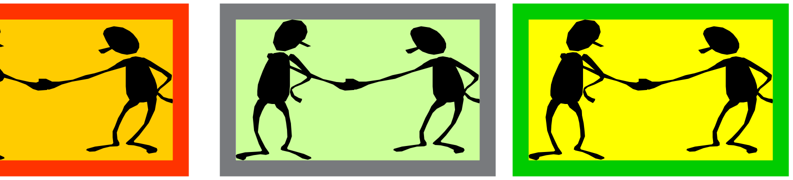


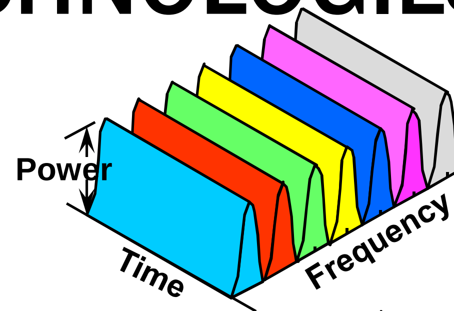
BASIC STRUCTURE OF A CELLULAR SYSTEM



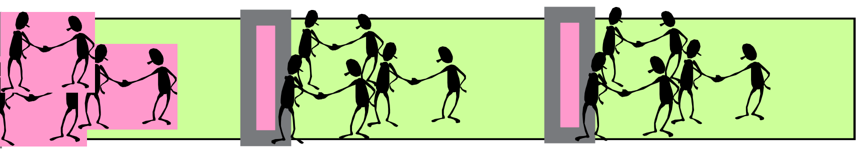
- obile communications are established through a network of radio base statio (“cell sites”)
- he radio network is connected to the PSTN (Public Switched Telephone Netwo

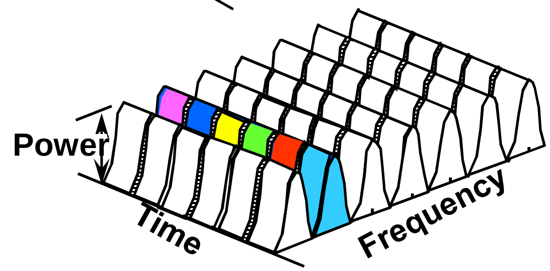
RELESS ACCESS TECHNOLOGIES



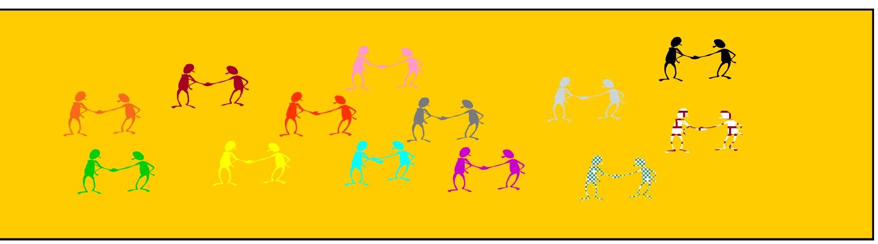


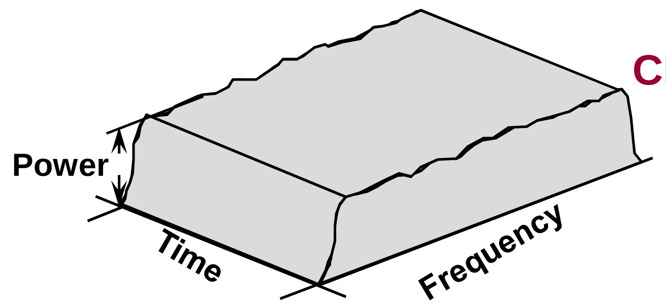
FDMA : Frequency Division Multiple Access



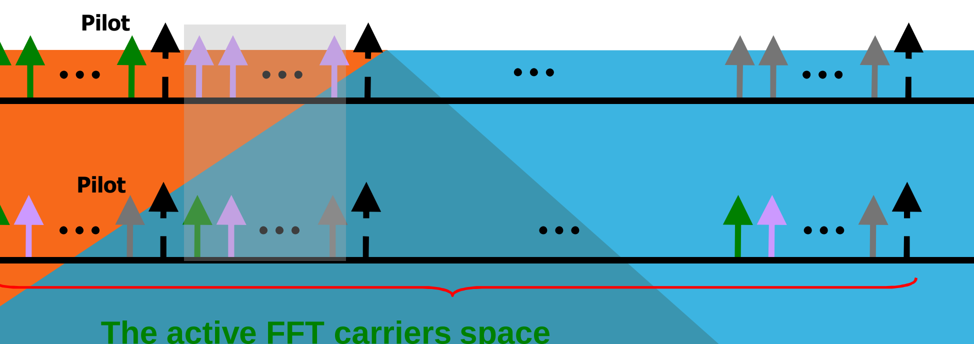


TDMA : Time Division Multiple Access

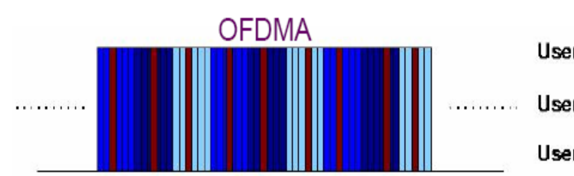




CDMA : Code Division Mu
A

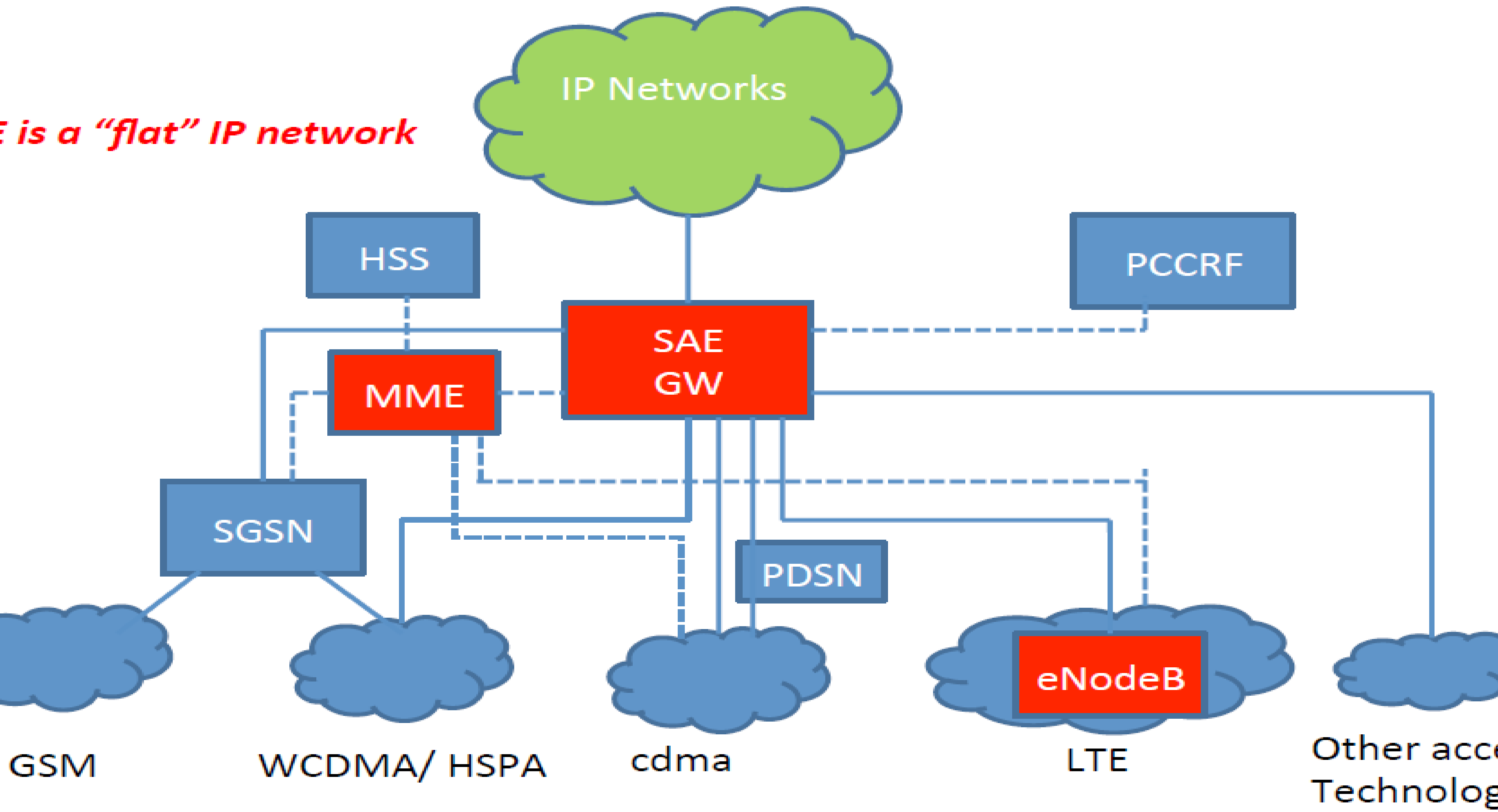


Orthogonal Frequency Division Multiplexing (Access)

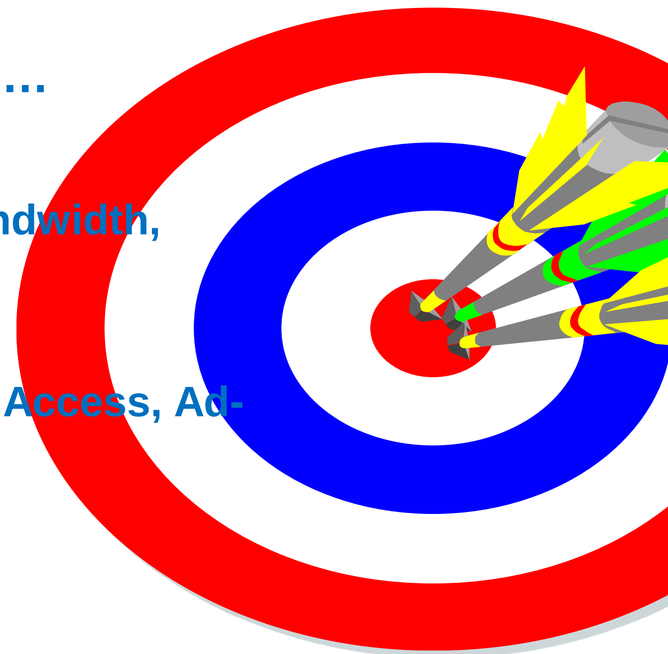


COMPARED TO GSM AND 3G

E is a "flat" IP network



VIRELESS DESIGN OBJECTIVES



nough Area Coverage

- Citywide, Statewide, Rural, Custom, In-building, Tunnels, etc…

aximum System Capacity

- Everyday Needs, Time of Disaster, Point of Disaster, Spectrum, bandwidth, Scalability

uality of Service

- Voice, Video and Data Interoperability, Security, Encryption, Priority Access, Ad-hoc, Tactically deployable, High Availability, 24/7 support

ost Efficiency

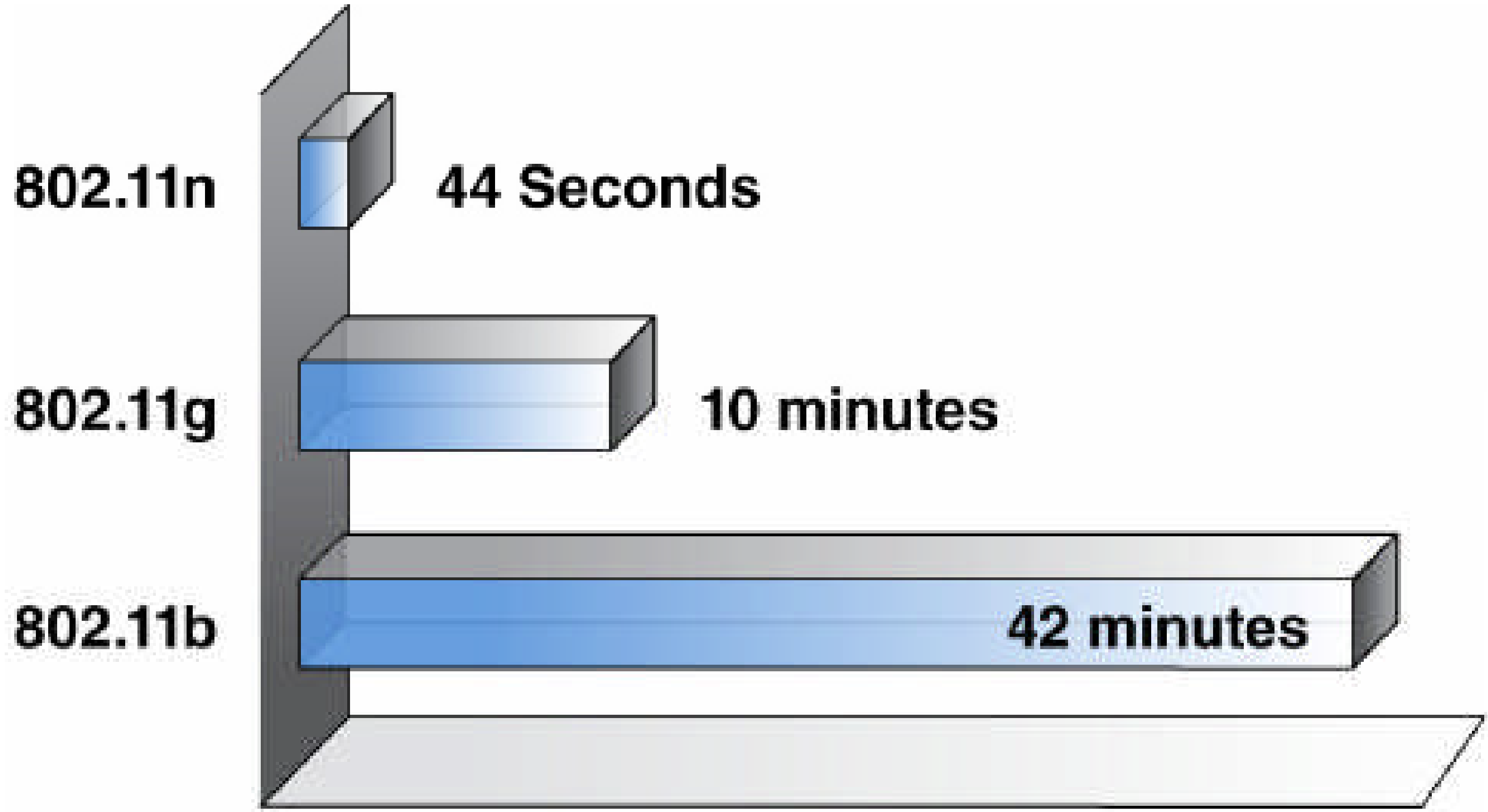
- Overestimation or under estimation, Own vs. Lease Spectrum,
- Commercial vs. Mission Critical, Services

xpansion Possibility

pectral Efficiency

- Cost-per-bit, throughput

DATA RATE COMPARISON



Time (Best Case) to Transfer 30-Minute HD Video.

A RATE WIRELESS INNOVATION

ear	Technology	Average Typical User Download Speed	Peak Netwo Download Sp
000	GPRS	20-40 kbps	115 kbps
001	UMTS	200-300 kbps	384 kbps
003	EDGE	70-136 kbps	236.8 kbps
005	HSPA	700-1.7 kbps	7.2 Mbps
009	HSPA+ (21 Mbps)	1.9-8.8 Mbps	21.6 Mbps
009	LTE (10 MHz)	6.5 – 26.3 Mbps	70 Mbps
010	HSPA+ (42 Mbps)	3.8-17.6 Mbps	42 Mbps
013	LTE-Advanced	??	1.2 Gbps

LTE Devices:

100 manufacturers have announced 948 LTE-enabled user devices, including frequency and carrier variants.

Most of the 948 LTE devices operate in the FDD mode. However, 200 devices can operate using the LTE TDD mode.

Smartphones continue as the largest LTE device category with almost 4 times as many products compared to the status in July 2012. LTE connected tablets and personal hotspots are the other fast growing product segments.

The most popular FDD bands are:

2600 MHz band 7 = 324 devices
800 MHz band 20 = 243 devices
2100 MHz band 1 = 215 devices
AWS band 4 = 203 devices
850 MHz band 5 = 80 devices

1800 MHz band 3 = 284 devices
700 MHz bands 12, 17 = 224 devices
700 MHz band 13 = 211 devices
900 MHz ban d 8 = 105 devices

4G IMT-ADVANCED CELLULAR SYSTEMS MUST FULFILL THE FOLLOWING REQUIREMENTS:

e based on an all- IP packet switched network.

ave peak data rates of up to approximately 100 Mbit/s for high mobility such as mobile acce
nd up to approximately 1 Gbit/s for low mobility such as nomadic/local wireless access.

e able to dynamically share and use the network resources to support more simultaneous use
er cell.

educed cost per bit

reduction in terminal complexity with an allowance for reasonable power consumption

sing scalable channel bandwidths of 5–20 MHz, optionally up to 40 MHz.

ave peak link spectral efficiency of 15 bit/s/Hz in the downlink, and 6.75 bit/s/Hz in the upli
meaning that 1 Gbit/s in the downlink should be possible over less than 67 MHz bandwidth).

ystem spectral efficiency of up to 3 bit/s/Hz/cell in the downlink and 2.25 bit/s/Hz/cell for ind
sage.

mooth roaming and handovers across heterogeneous networks.

he ability to offer high quality of service for next generation multimedia support

CHALLENGES

martphones becoming "typical" phone and tablets (defining the nature of computing)

more than 1 million mobile applications, consumption of internet-based shows and movies from a wide array of source
cluding youTube, amazon, netflix,.... Cutting cord and using wireless broadband connection (30% of U.S. households
ireless phone only), More and more content streaming over wireless networks

work Congestion

t takes a handful of users in a coverage area streaming video to consume the entire sector capacity

❖1.4 bt/hz/s with 10 Mhz BW, 14 Mbps capacity . Assuming music streaming (100-200kbps) and video streaming (2
5mbps)

neven distribution of speeds over the coverage are because of near and edge location

emtocell and Wifi

arriers in absence of new spectrum would have to increase prices and impose data-use resritriction

tery life

TE devices (radio at high data rate) consume 5% to 20% more power than previous-generation phones

high power demand: displays, data consumptions, simultaneous multi radio operation, immature chip set design,....

ming : Operators using widely different bands .

S carriers are rolling out LTE in 700Mhz, EU is likely to use 2.6 GHz, Japan is using 1.5 GHz and 2.1 GHz, and China u
ifferent set of LTE ,TDD, at 2.3 and 2.5 GHz.

LTE network strategies and technical hurdles

D-LTE and LTE FDD are seen as complementary. The choice between the TDD and FDD versions of LTE is enerally dictated by the available spectrum

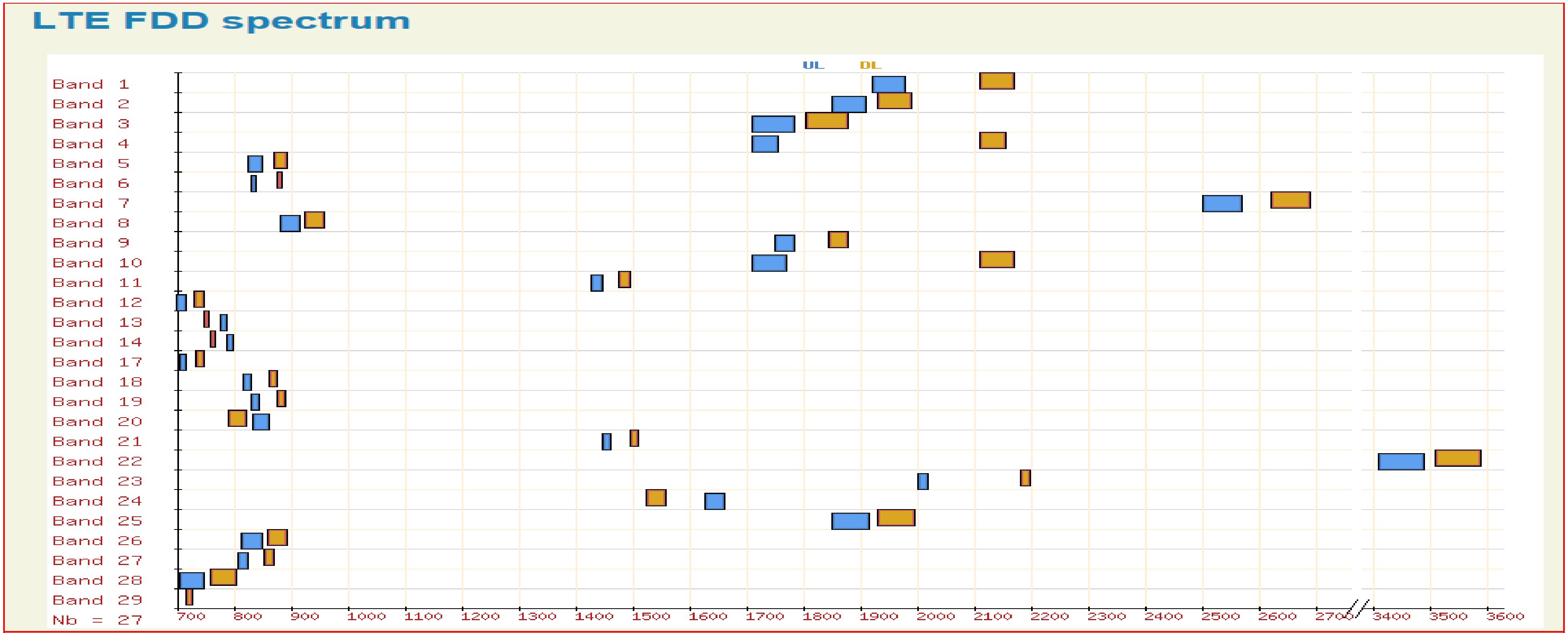
D-LTE real take-off is expected when India and China implement the technology. The former is expected to start ommercial service end-2011, early 2012.

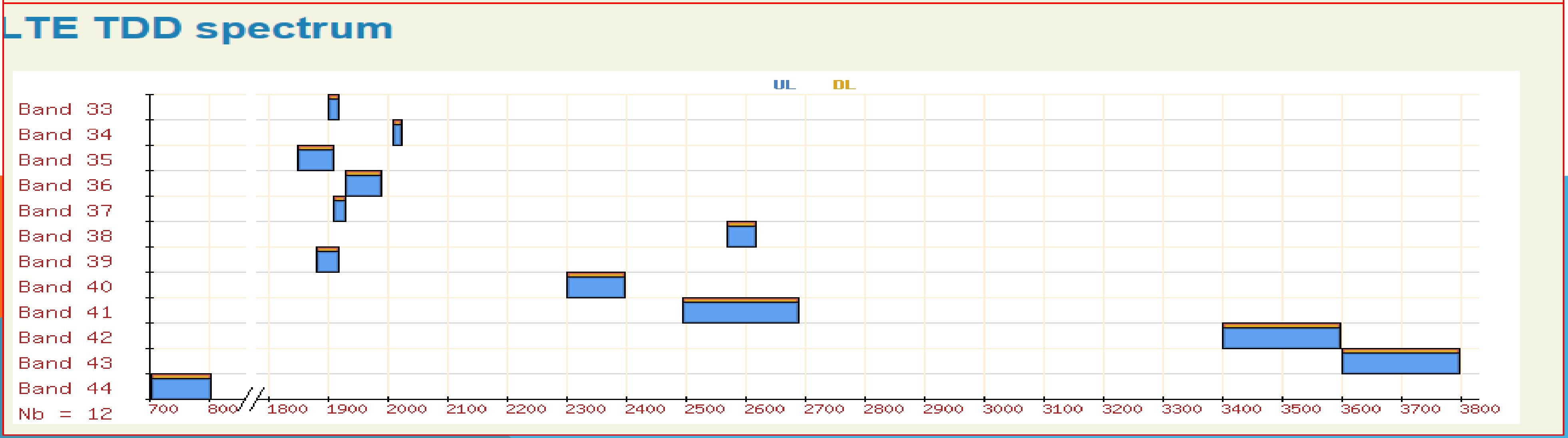
nterest in LTE-Advanced is increasing as DOCOMO, SK Telecom in South Korea and Clearwire have announced eir intention to rapidly implement this evolution of the technology. The 2013 objective set up by Clearwire and SK elecom shows a two-year shift of the initially expected launch of LTE-Advanced. Carrier aggregation is expected to e a major enhancement for the downlink.

oLTE is slowly being implemented by mobile operators. Front-runners MetroPCS and Verizon in the USA will plement VoLTE in 2012.

ransition from mobile WiMAX to TD-LTE is accelerating as support to Mobile WiMAX wanes from both equipment endors and operators

emtocells will bring additional capacity and play a very significant role in LTE development in the medium to long rm. SK Telecom and NTT DOCOMO have already announced their plans to deploy LTE femtocells rapidly.

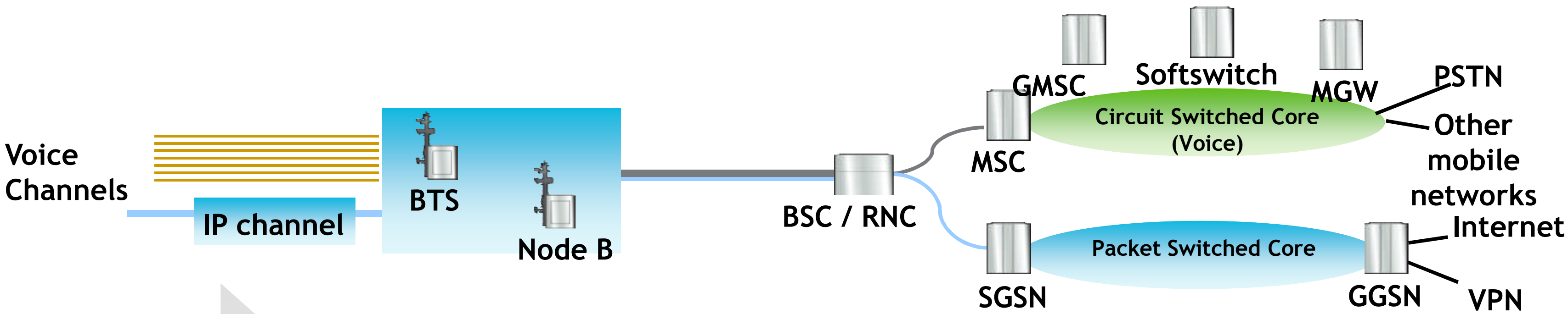

LTE FDD spectrum
UL
DL
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Band 7
Band 8
Band 9
Band 10
Band 11
Band 12
Band 13
Band 14
Band 17
Band 18
Band 19
Band 20
Band 21
Band 22
Band 23
Band 24
Band 25
Band 26
Band 27
Band 28
Band 29
Nb = 27
700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 3400 3500 3600


LTE TDD spectrum
UL
DL
Band 33
Band 34
Band 35
Band 36
Band 37
Band 38
Band 39
Band 40
Band 41
Band 42
Band 43
Band 44
Nb = 12
700 800 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500 3600 3700 3800

LVED PACKET CORE (EPC): A NEW ALL-IP MOBILE CORE FOR LTE

3G

- CDMA
- GSM
- GPRS
- EDGE
- UMTS
- HSPA



hat is EPC ?

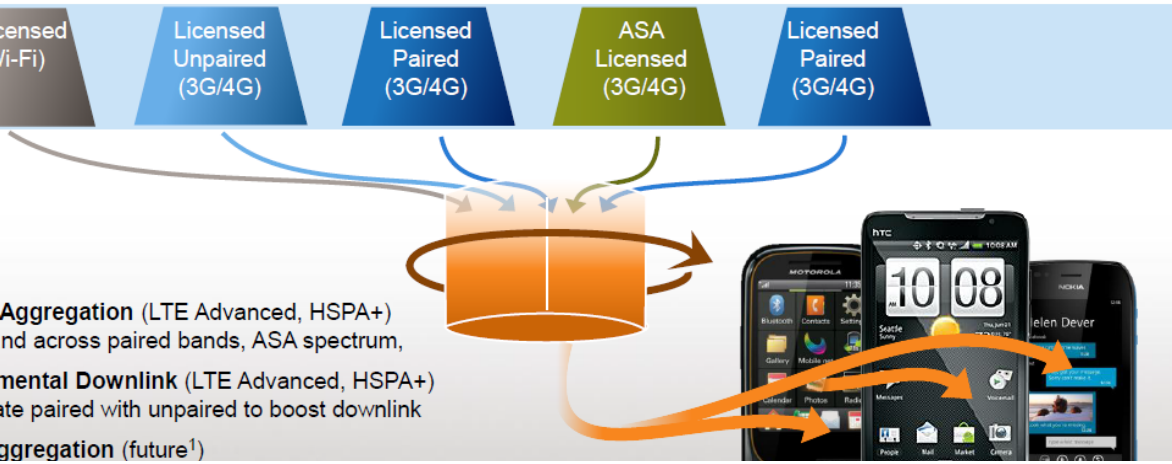
New IP based mobile core network introduced with LTE

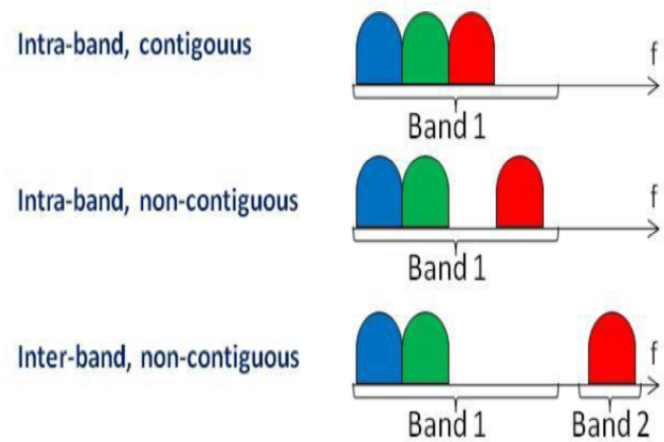
- End-to-end IP Mobile Service Delivery Architecture
- New elements:
  - *Serving Gateway and PDN Gateway*
  - *Mobility Management Entity*
  - *Packet Data Network Gateways*

LTE+EPC

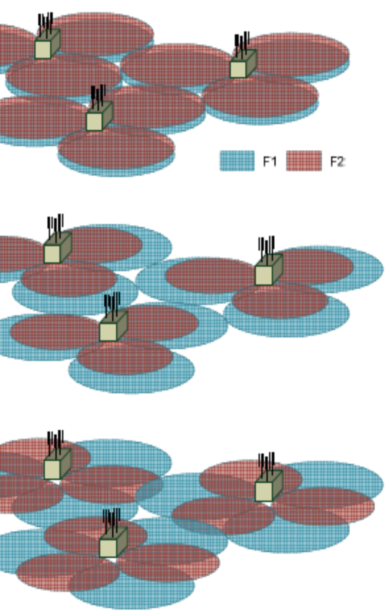
All IP transformation = New Svcs and Better Performance for Enterprises

TRUM AGGREGATION MAKES USE OF ALL SPECTRUM ASSETS

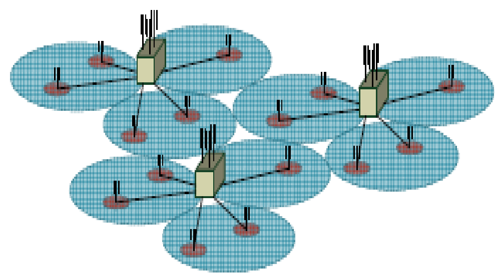


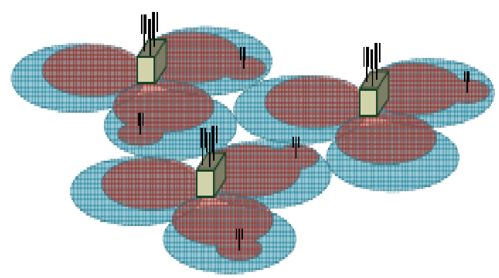


A deployment scenario



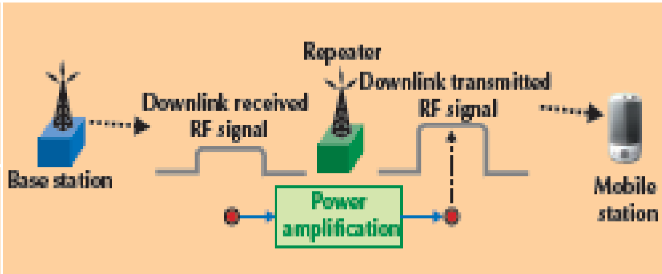
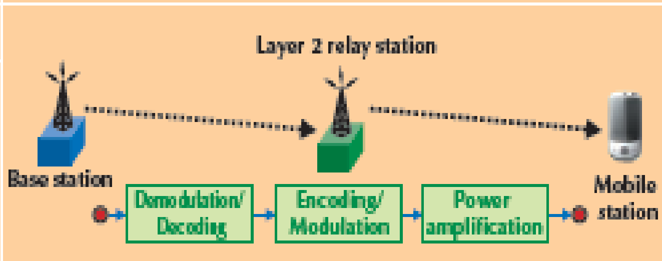
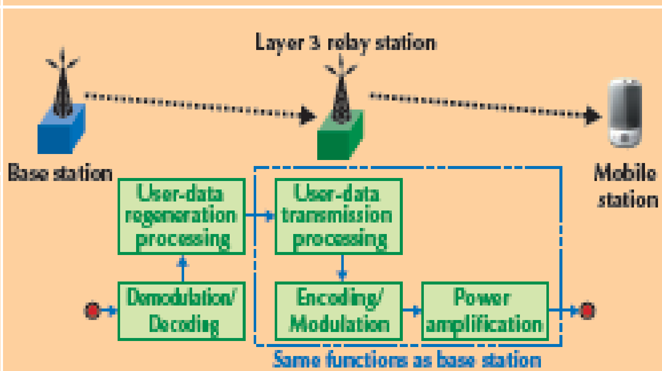
- Scenario 1
  - F1 and F2 cells are co-located and overlaid, providing nearly the same coverage
  - Likely scenario when F1 and F2 are of the same band
- Scenario 2
  - F1 and F2 cells are co-located and overlaid, but F2 has smaller coverage due to larger path loss
  - Likely scenario when F1 and F2 are of different bands
- Scenario 3
  - F1 and F2 cells are co-located but F2 antennas are directed to the cell boundaries of F1 so that cell edge throughput is increased
  - F1 provides sufficient coverage but F2 potentially has holes, e.g., due to larger path loss
  - Likely scenario when F1 and F2 are of different bands





- Scenario 4
  - F1 provides macro coverage and on
    Remote Radio Heads (RRHs) are use
    provide throughput at hot spots
  - Likely scenario when F1 and F2 are c
    different bands
- Scenario 5
  - Similar to scenario #2, but frequenc
    repeaters are deployed so that cove
    extended for one of the carrier frequ

EATURES OF VARIOUS RADIO RELAYS TECHNOLOGIES

ay gy		Advantages/Disadvantages	Overview
lay	Plus	• Simple and inexpensive functions • Minimal impact on standard specifications (specifications on repeater performance already defined in LTE Rel. 8)	
	Minus	• Noise is amplified simultaneously with desired signals	
lay	Plus	• Elimination of noise	
	Minus	• Processing delay due to modulation/demodulation and encoding/decoding • Radio control functions must be added between base station and relay station	
lay	Plus	• Elimination of noise • Small impact on standard specifications	
	Minus	• Processing delay due to modulation/demodulation and encoding/decoding • Layer 3 processing delay (user-data regeneration processing, etc.)	

Scenario	Deployment	Number of hops
Rural area	Extend coverage to mountainous regions, sparsely populated areas	1 hop
Wireless backhaul	Extend coverage to mountainous regions, sparsely populated areas, remote islands	1 hop, multiple hops
Emergency or temporary coverage	Provide temporary coverage at times of disasters, events, etc.	1 hop, multiple hops
Urban hot spot	Expand coverage and enhance throughput in urban areas with high concentrations of traffic	1 hop
Dead spot	Fill coverage hole	1 hop, multiple hops
Indoor hot spot	Expand coverage to indoor environments and enhance throughput	1 hop
Group mobility	Install relay stations in public vehicles to reduce handover and location-registration control signals	1 hop

Layer2 relay Technology

oMP: effective way of managing inter-cell interference, and has been garded as a key technology of LTE-Advanced.

ordinated multipoint transmission and reception oMP) or network MIMO

Perform Signal processing for coordinated ransmission and reception by multiple cells to one r more UE

Advanced version of MIMO (cooperative MIMO) or higher Cell edge data rate and average cell pectral efficiency by implementing inter-cell /intra-ell orthogonalization on the uplink and down link

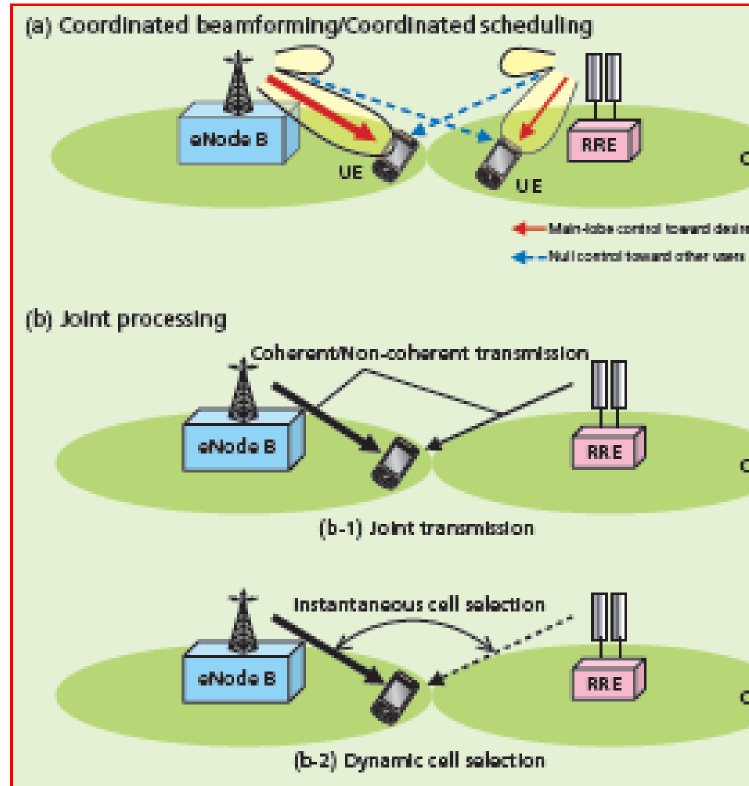


Figure 8 Downlink CoMP transmission

eral possible coordination among the access ints

ordinated beamforming/scheduling (user data are transmitted only m one single cell)

int processing (JP) (multiple nodes transmit data to UE)

- Joint transmission
- Dynamic Cell Selection (DCS)

LTE COMP - THE ADVANTAGES

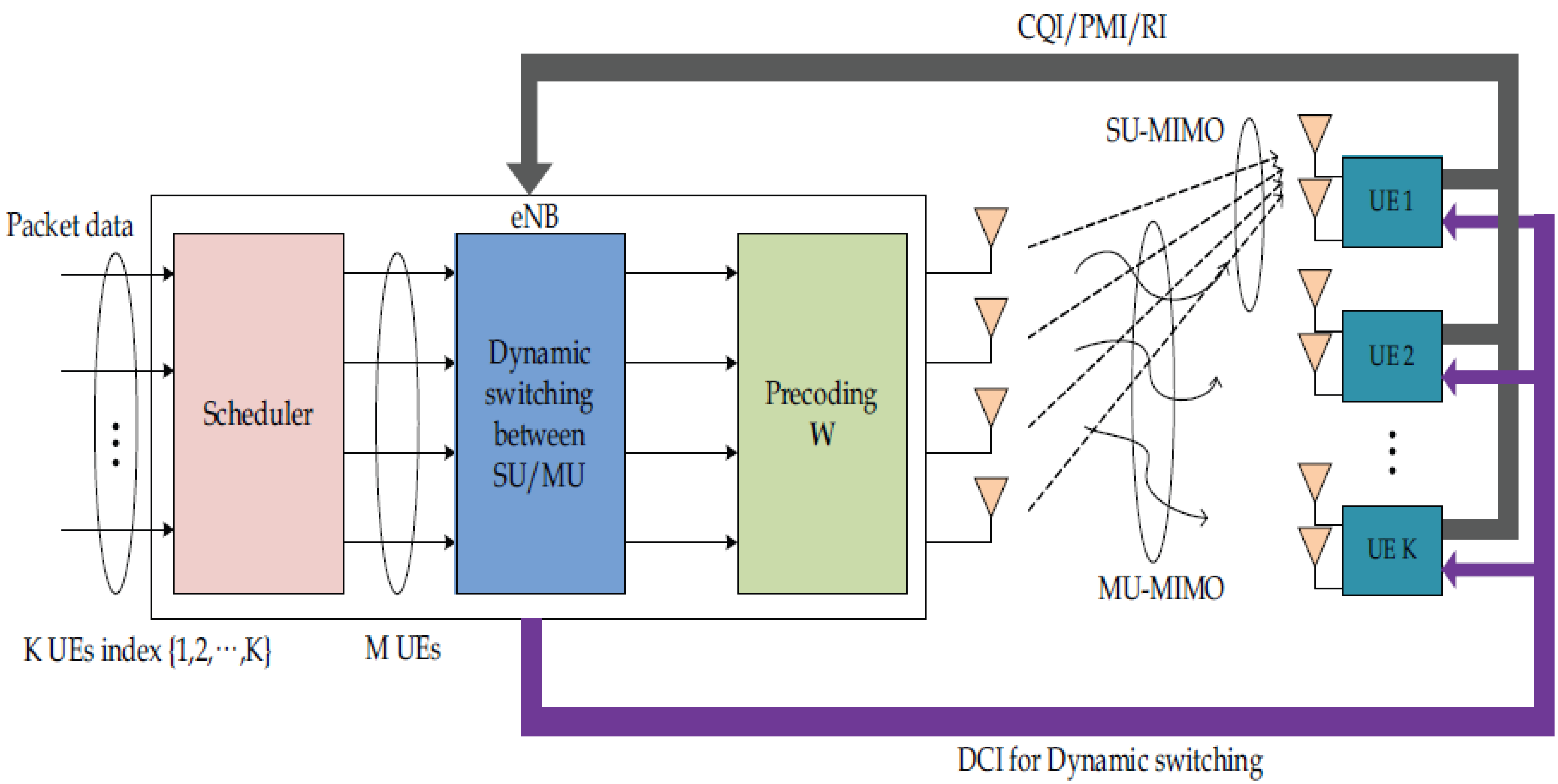
Makes better utilization of network: **By providing connections to several base stations at once, using CoMP, data can be passed through least loaded base stations for better resource utilization.**

Provides enhanced reception performance: **Using several cell sites for each connection means that overall reception will be improved and the number of dropped calls should be reduced.**

Multiple site reception increases received power: **The joint reception from multiple base stations or sites using LTE Coordinated Multipoint techniques enables the overall received power at the handset to be increased.**

Interference reduction: **By using specialized combining techniques it is possible to utilize the interference constructively rather than destructively, thereby reducing interference levels.**

SU/MU MIMO dynamic Switching



F-CONFIGURING AND SELF-OPTIMIZING NETWORKS (SO

P suggests to implement following functions:

etection of unintended holes in the coverage (planned by the operato

erform coverage optimization, including DL/UL channel coverage

bility to balance the trade-off between coverage and capacity

e solution is implemented, it would result in :

ntinuous, optimized and matched UL and DL coverage

timized DL and UL capacity of the system

lanced tradeoff between coverage and capacity

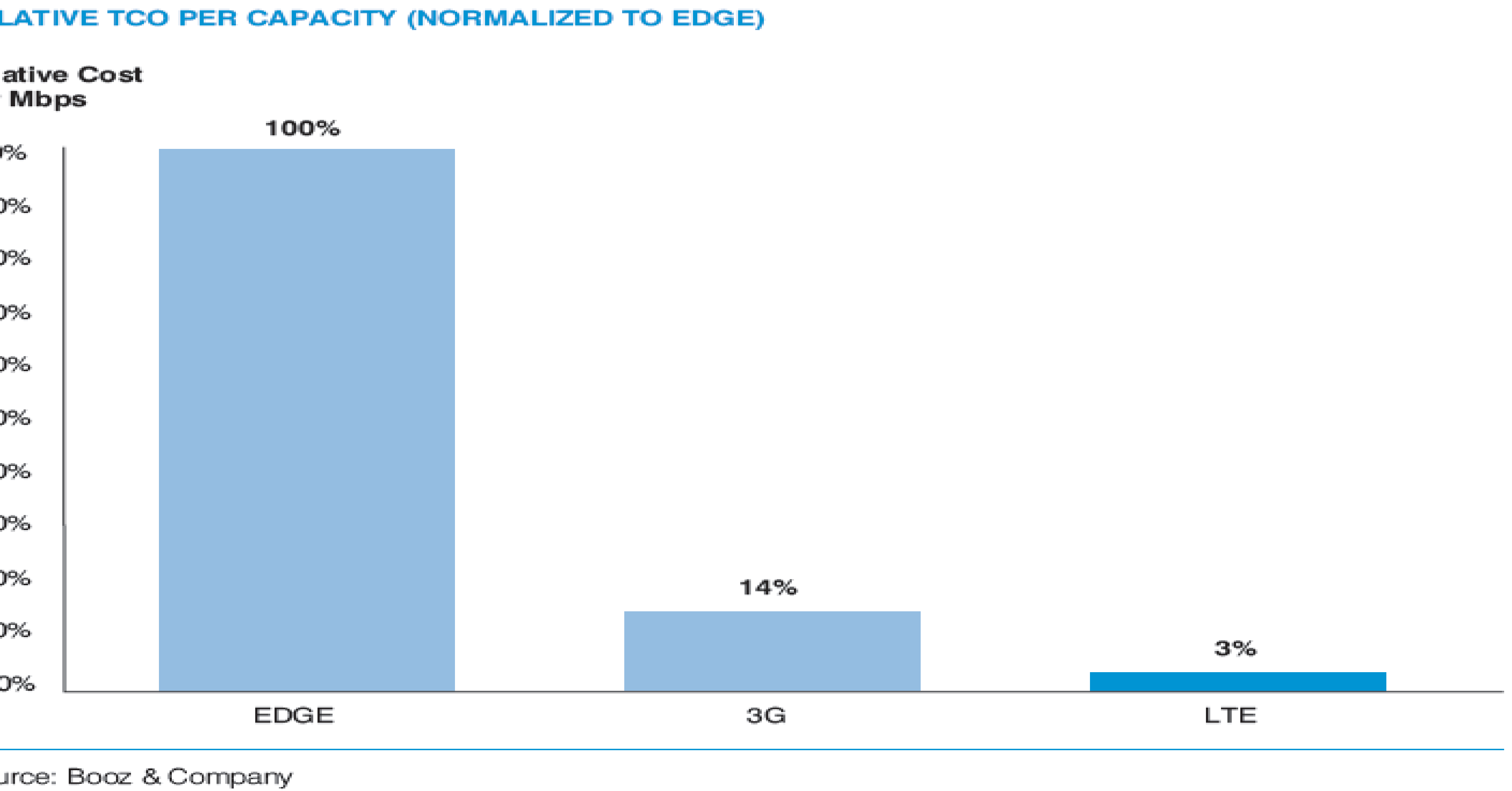
erference reduction

ntrolled cell edge performance

nimized human intervention in network management and optimization tasks

ergy savings

LTE Offers Significantly Lower Cost per Mbps of Capacity



onclusion on LTE strategies

TE is mainly implemented for additional capacity

TE is also driving costs down for mobile operators

LTE will dominate the 4G field: the LTE ecosystem is narrowing the mobile WiMAX market

LTE devices availability is a hurdle (2.6 GHz band) today in Western Europe

Spectrum fragmentation for LTE is slowing down roaming prospects

More network sharing will be encouraged by spectrum scarcity in the digital dividend and business mode ustainability in specific developing markets

oice (VoLTE) is mainly a long-term concern for most operators

TE femtocells will play a key role in LTE deployments

TE-Advanced will be here sooner than expected: first real-scale deployments are expected in 2013. Last ear, 2015 was the target for LTE-Advanced deployments.

TD-LTE is now seen as a complement to LTE FDD in many countries

TE in the digital dividend can be used as a substitute to the fixed network as shown in Germany, Australi nd planned by Verizon Wireless

he LTE wholesale model is developing worldwide with many implementations around the world

5G

adaptive array transceiver capable of transmitting data at a rate of 1.056 Gbit/s at a range of up to 2 km (1.2 miles) in the tricky millimeter waveband.

At 28 GHz, Samsung's technology is operating just outside of the band normally considered the millimeter band, which ranges from 30 to 300 GHz. Electromagnetic radiation has wavelength of between 1 and 10 mm, hence the name.

64-antennae transceiver, which transmitted data at 1.056 Gbit/s, "can be a viable solution for overcoming the radio propagation loss at millimeter-wave bands," and would allow the transmission of 3D films and games, ultra HD video and, intriguingly, "remote medical services."

Key Concepts of 5G

a. Real wireless world with no more limitation with access and zone issues.

b. Wearable devices with AI capabilities.

c. Internet protocol version 6 (IPv6), where a visiting care-of mobile IP address is assigned according to location and connected network. MPTCP enabled architecture.

d. One unified global standard.

e. Pervasive networks providing ubiquitous computing: The user can simultaneously be connected to several wireless access technologies and seamlessly move between them . These access technologies can be a 2.5G, 3G, 4G or 5G mobile networks, Wi-Fi, WPAN or any other future access technology. In 5G, the concept may be further developed into multiple concurrent data transfer paths.

f. Cognitive radio technology, also known as smart-radio: allowing different radio technologies to share the same spectrum efficiently by adaptively finding unused spectrum and adapting the transmission scheme to the requirements of the technologies currently sharing the spectrum. This dynamic radio resource management is achieved in a distributed fashion, and relies on software defined radio.

g. High altitude stratospheric platform station (HAPS) systems.

Here is why Samsung's announcement is a hyperbole(1/2)

- **Its experiment achieved a data rate of 1.056 Gbps. This is not several hundred times of today's fastest 4G LTE networks. According to a study, even AT&T T -0.61% which does not have the fastest network in the world achieved 57.7 Mbps of maximum download speeds in real life. Samsung's test achieved only about 18 times AT&T's max average speed.**
- **Transmissions in the millimeter wave band do not pass through building walls.**
- **Transmissions in the millimeter wave band are attenuated even by trees.**
- **Transmissions In the millimeter wave band are easily absorbed by rain drops, humidity has significant impact.**
- **Samsung claims to have used a 64 element antenna. There are no more details about this antenna. Considering the claims Samsung is making, it appears to me that transitioning such an antenna from a mere outdoor experiment to the point of miniaturization so that it can be used in an actual phone may be not be easily achievable.**

Here is why Samsung's announcement is a hyperbole(2/2)

Transmissions in the millimeter band are typically used in line-of-sight applications because they do not bend or reflect well.

There is a Doppler shift when the recipient is moving and this can be a significant issue.

At these high frequencies, a phone can be severely impacted by shadowing caused by the user's body.

Although 4G has become part of our daily vocabulary, there is no 5G standard that exists today. 5G is simply a generic term for the next generation network. In general, in the world of communications, standards are developed long before commercialization. There is no 5G standard published by any recognized body.

Samsung itself projects that the technology may not be ready until 2020.

802.11 ac

The industry is now exploring opportunities to increase wireless throughput beyond was is possible using 802.11n technology. The proposed 802.11ac amendment to the IEEE 802.11 specification is currently in draft stage, with final approval targeted for December 2013. Its main goals are to achieve a maximum Multi-Station (Multi-STA) throughput of at least 1 Gbps and a maximum single link throughput of at least 500 Mbps. These higher rates are motivated by the continuing trend to transition devices and applications from fixed links to wireless links and by the emergence of new applications with ever higher throughput requirements.

Unlike existing technologies that operate in the 2.4 GHz band and 5 GHz band or both, 802.11ac operates strictly in the 5GHz band, but supports backwards compatibility with other 802.11 technologies operating in the same band (most notably 802.11n). 802.11ac relies on a number of improvements in both the MAC and Physical Layer (PHY), including Increased bandwidth per channel, an increased number of spatial streams, higher-order modulation (256 Quadrature Amplitude Modulation, or QAM), and Multi-User Multiple Input Multiple Output (MU-MIMO). 802.11ac retains a number of advanced digital communication concepts that were first introduced in 802.11n, including space division multiplexing, LDPC, shortened guard interval (short GI), Space-Time Block Coding (STBC), and explicit-feedback transmit beamforming

Operators' considerations

Innovation Cycles becoming shorter

Time-to-market pressures are increasing

The risk of upfront investment into new technologies before they prove to make business sen of

The broad set of technologies needed to offer state-of-the-art services before to end-custome without loading them to maximum capacities

The network is not a unique selling point to end-customers anymore

Outsourcing, merging, and infrastructure sharing can increase operator's operations cash flow

No longer the ownership of network infrastructure to be the most precious asset.

Declining revenue combined with the new growth forced operators to consider new business model

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