Reflections, Challenges, & Beyond

Future of Wireless

C K Toh November 2013

Outline

- Wireless Today
- Wireless Challenges
- Wireless Beyond 2020 - 2050
- Conclusion

My Talk – Disclaimer…..

- Let me shield myself first!
- **Will not talk:**
  - In detail PHY, MAC, PROTOCOLS, etc (bcos u know better)
  - In detail EU programs or standards (bcos u know better)
  - Ad hoc networks (even I know a lot)
- **Will talk:**
  - A "broader" perspective to look beyond the "norm" – perhaps beyond 2020…

Wireless Today

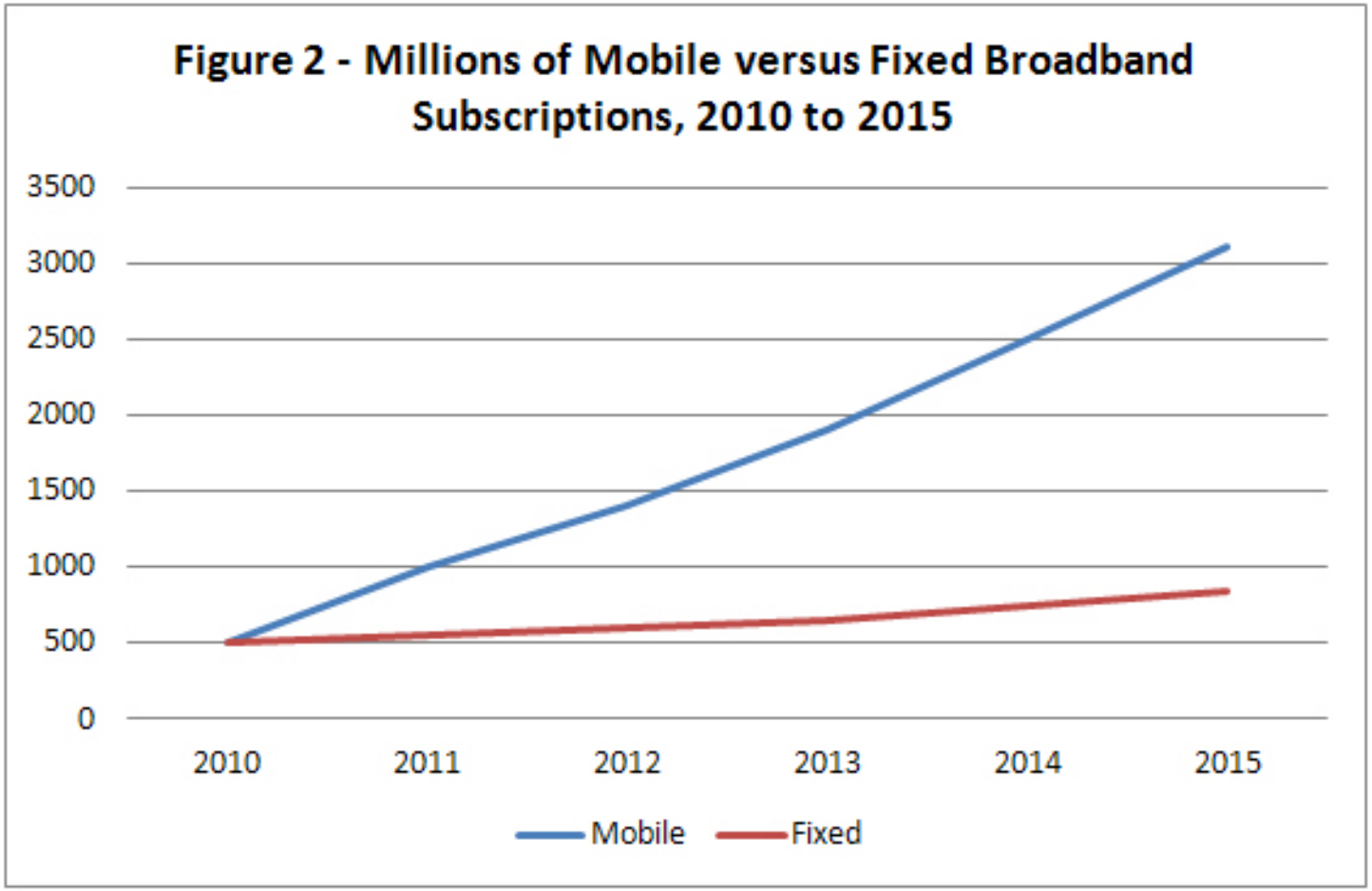
- Wireless is “King”
- Wireless connections surpass wired connections
- Wireless users keep increasing
- Wireless is affordable
- Wireless is (has always been) invisible..

Wireless Today - World Population

- Scale 7Billion
- Each user x2
- 14 Billion device

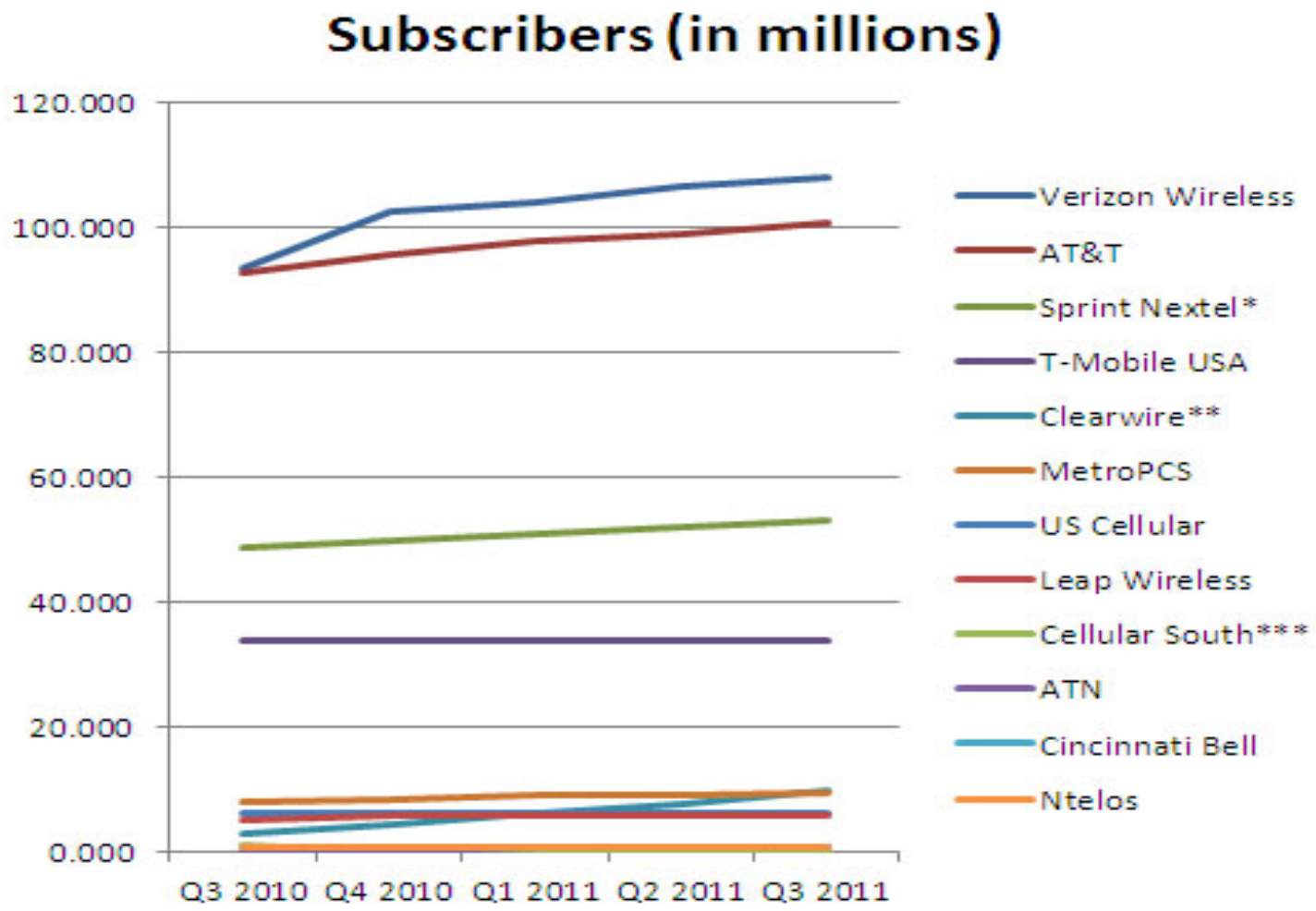
Rank	Country	Population	Date	% of world population
–	World	7,122,500,000	November 6, 2013	100%
1	China[8]	1,360,910,000	November 6, 2013	19.1%
2	India	1,236,080,000	November 6, 2013	17.4%
3	United States	317,008,000	November 6, 2013	4.45%
4	Indonesia	237,641,326	May 1, 2010	3.34%
5	Brazil	201,032,714	July 1, 2013	2.82%
6	Pakistan	184,717,000	November 6, 2013	2.59%
7	Nigeria	173,615,000	July 1, 2013	2.44%
8	Bangladesh	162,518,015	July 16, 2013	2.14%
9	Russia	143,500,000	September 1, 2013	2.01%
10	Japan	127,300,000	October 1, 2013	1.79%

Wireless Today – Wireless vs. Fixed



Sources: Wireless Intelligence, July 2011; Informa Telecoms & Media (WBIS), July 2011

Wireless Today - Mobile Subscribers



Wireless Today – Observations

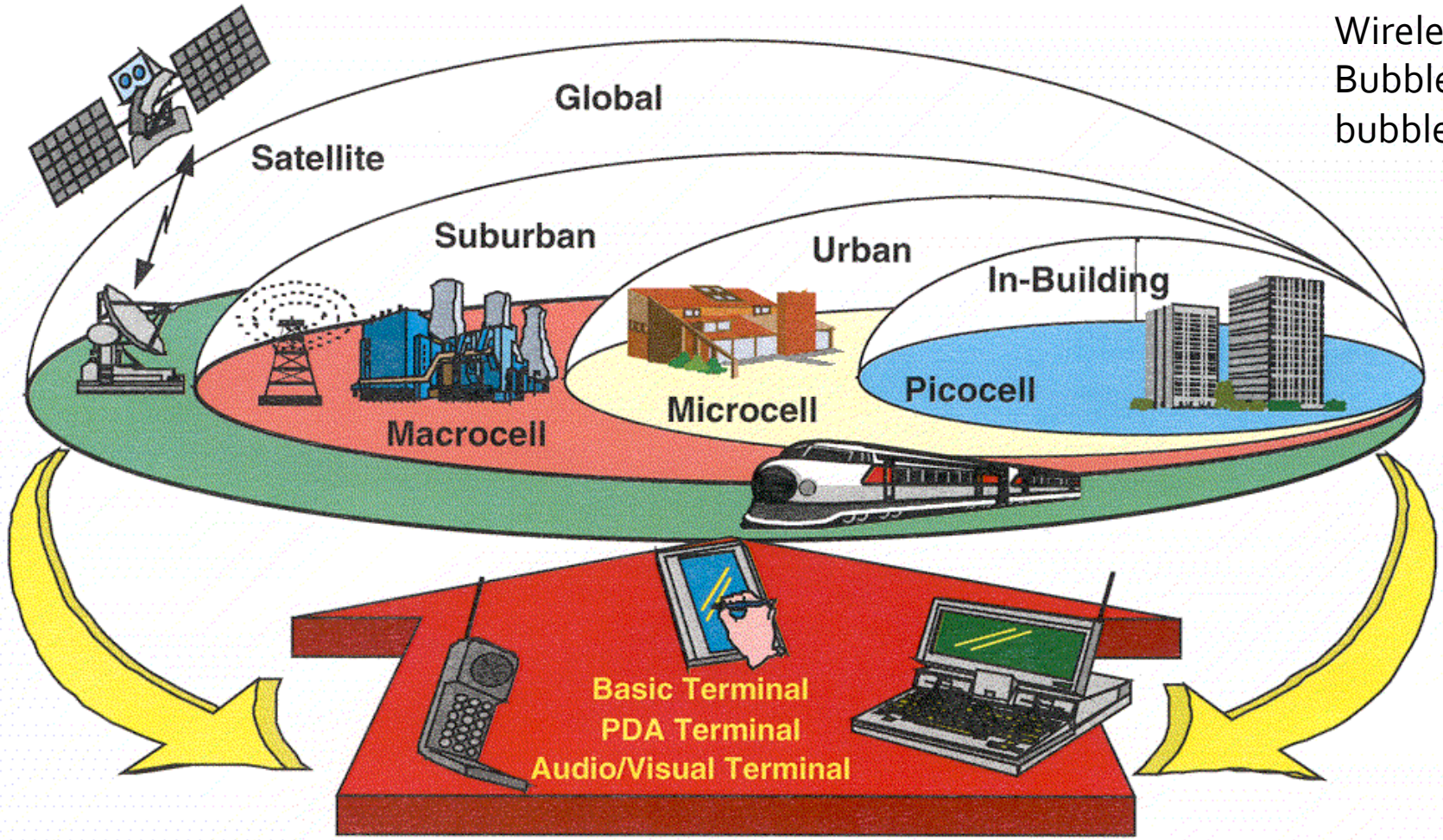
- Progress made in many ways
- From hardware to software
- From protocols to modulation
- From indoor to outdoors
- 2 important observations:
  - Wireless penetration is **unstoppable**
  - Wireless is taking place is **many forms**

Wireless Today - Unstoppable

WIRELESS PENETRATION UNSTOPPABLE

- BT
- WiFi
- WiMax
- HSDPA
- UMTS
- LTE
- etc

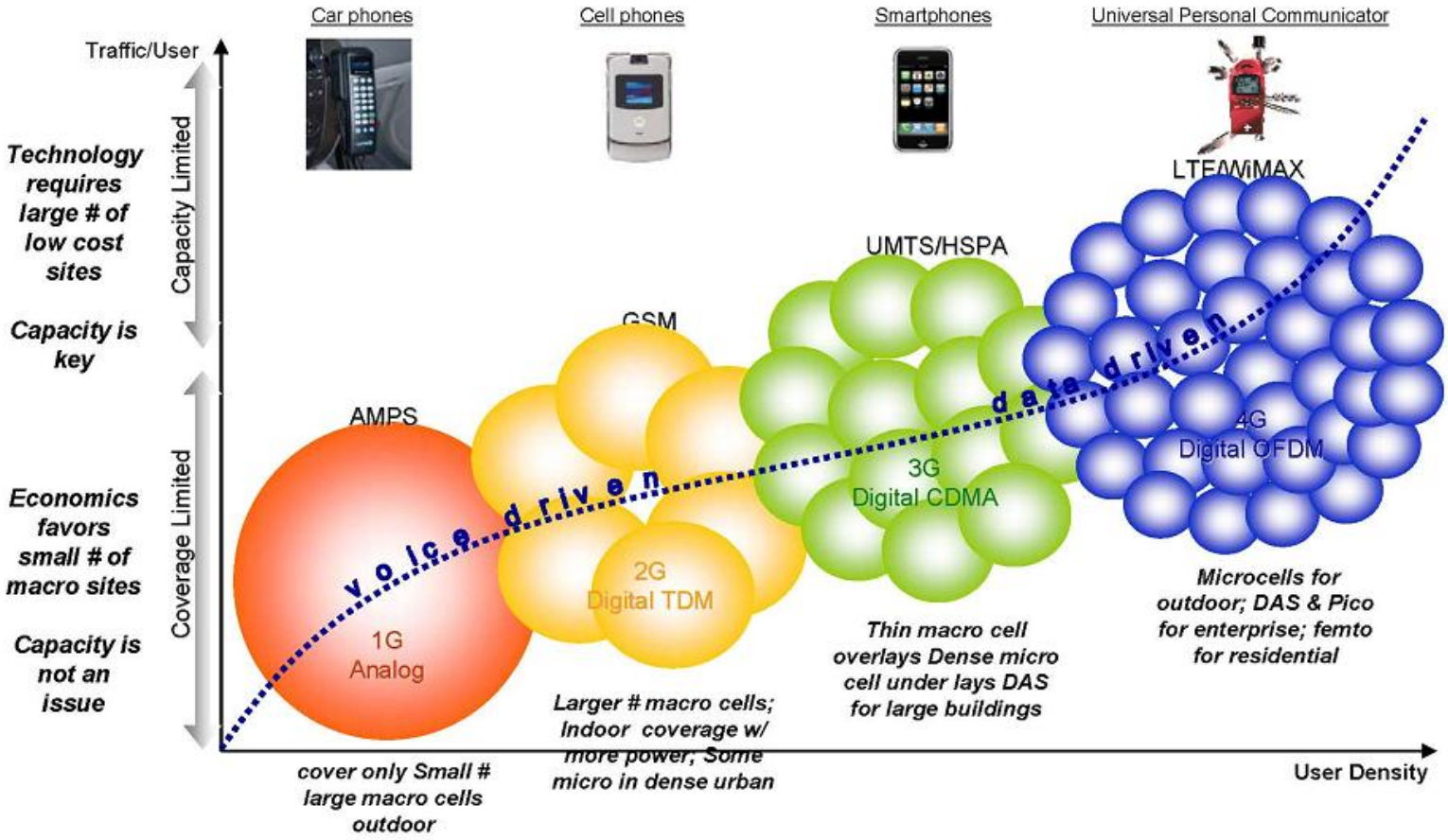
Wireless Today - Bubbles



Wireless Bubbles of bubbles

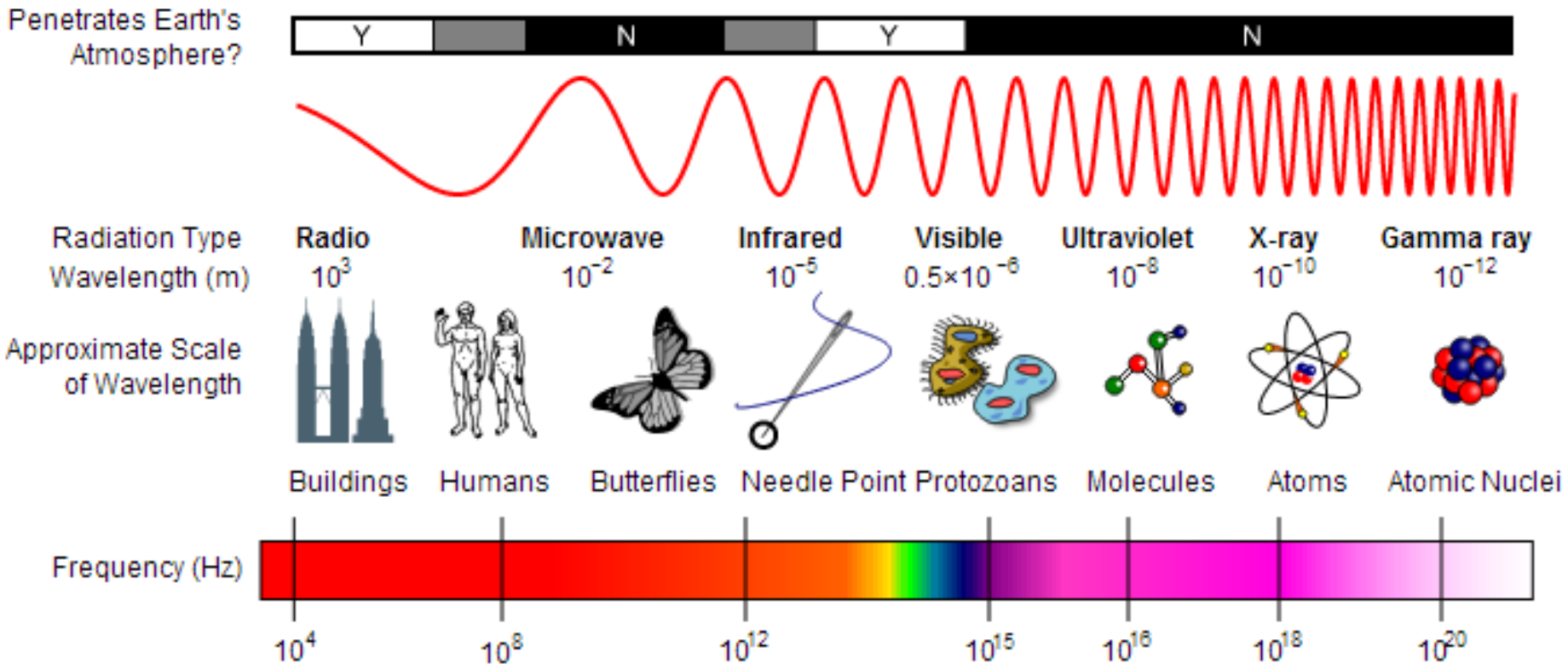
Wireless Today – Many forms

- Wireless evolves in many forms



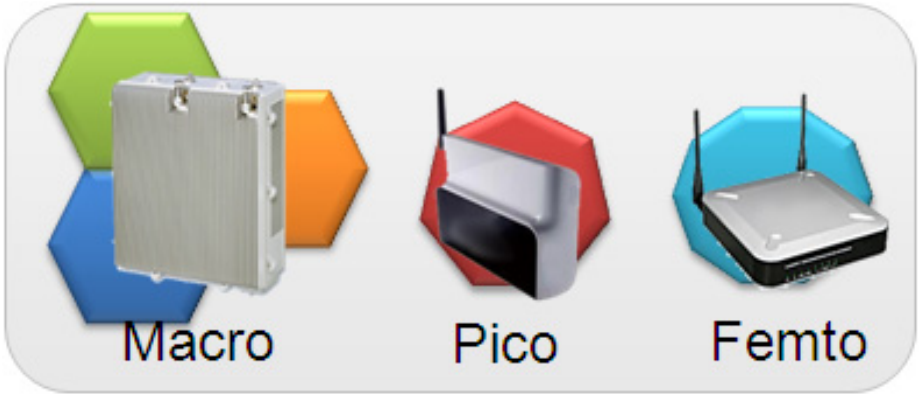
Wireless Today - Spectrum

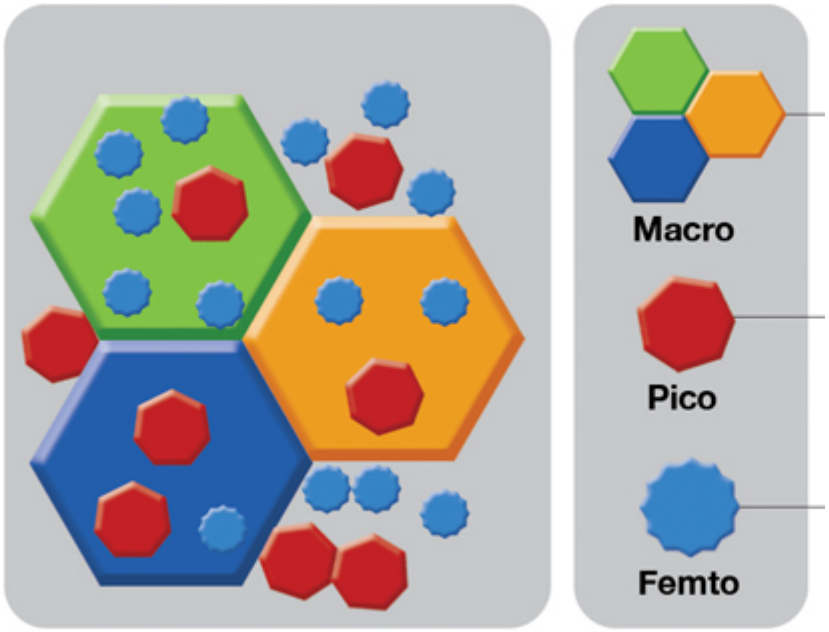
- We're squeezing every juice out of EM spectrum



Wireless Today – Cells of cells

- Cells of Cells
  - Beside
  - Over
- Spatial Reuse
- Coverage vs. capacity



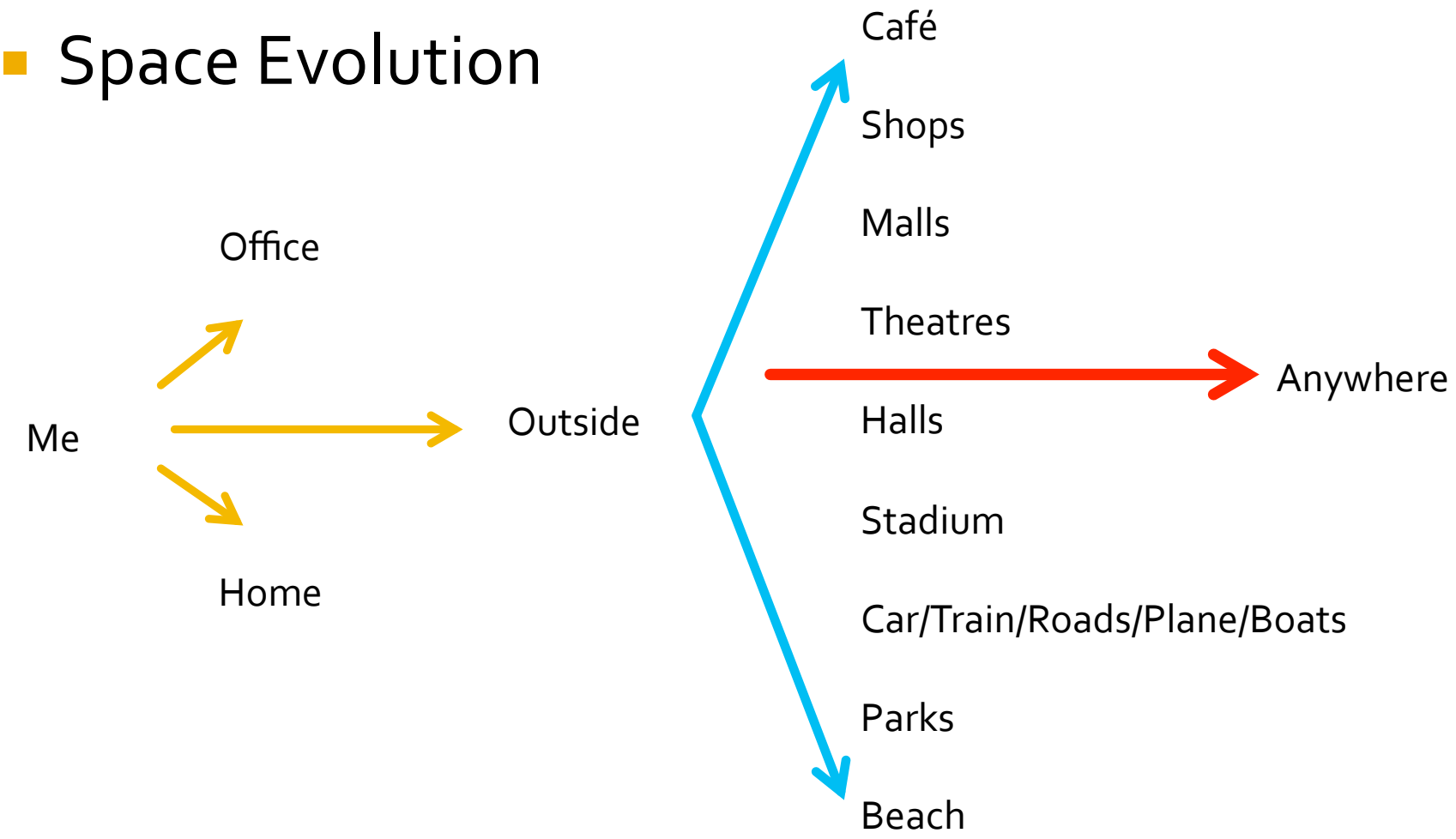


Wireless Today – Me & Beyond

- We are expanding the boundary of wireless
- From us:
  - Self-centric
- To outside us:
  - World-centric

Wireless Today – Everywhere

- Space Evolution



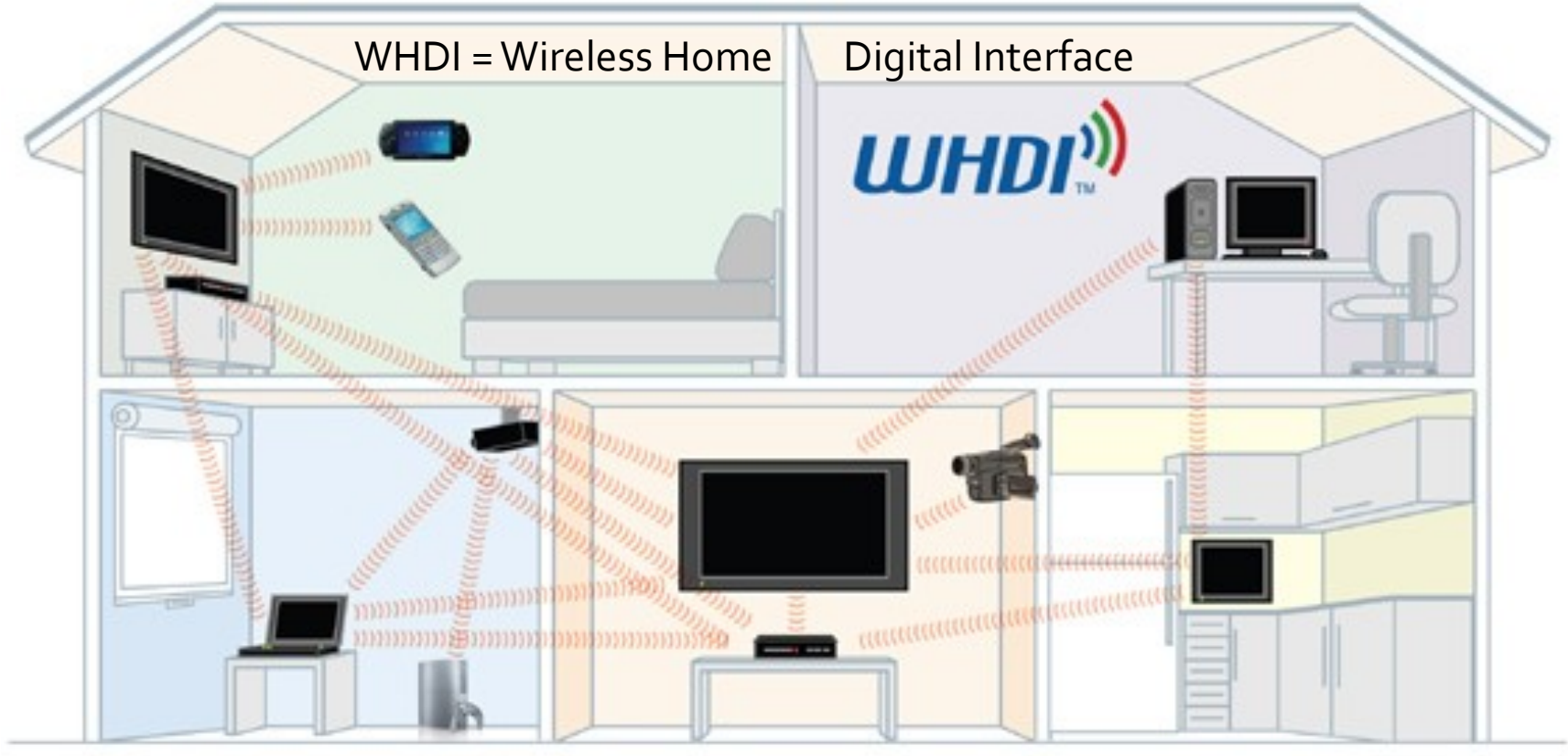
Wireless Today: Who, What?

- TV
- MOBILE DEVICES
- WATCH
- CARS
- PLANES
- TRAINS
- LAPTOPS (if it survives)
- ETC

Wireless Today

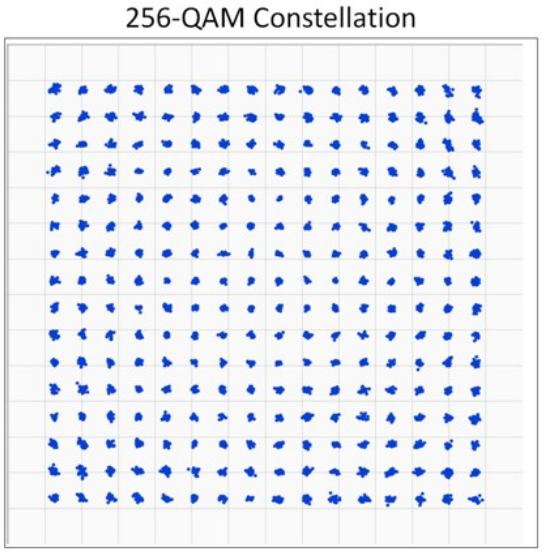
- Wireless at Home

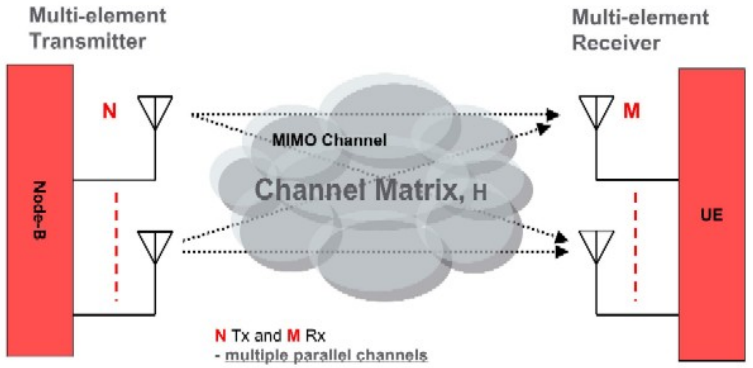
Computer/Phone/SUB Video to HDTV
Multi-source, 5GHz, 3 GBps, 5x4 MIMO



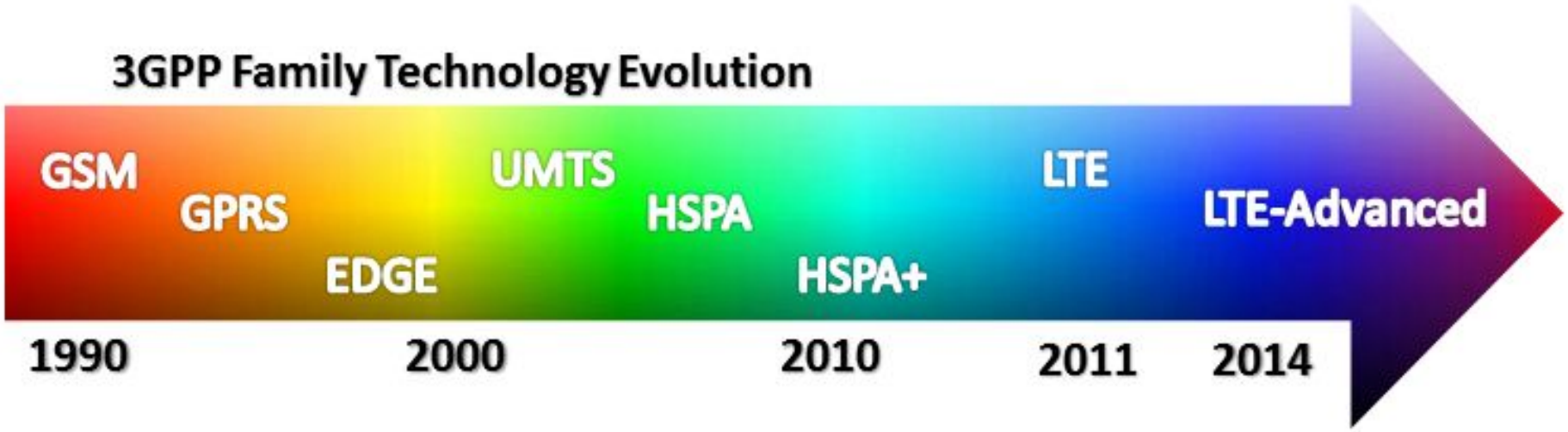
Wireless Today - Progress

- Many innovations made in wireless:
  - Adaptive modulation
  - Adaptive beam forming
  - MIMO antennas
  - Space Time Coding
  - Digital RF processing
  - OFDM Multiple Access technology
  - Advanced baseband processing
  - Cooperative Communications
  - Dynamic Spectrum Management
  - Multi-mode Multi-Band
  - .....





Wireless Today: 3G



	Technology			
1G	Analog	CMRT	AMPS	
2G	Digital Circuit Switched	D-AMPS	GSM	CDMA
2.5G	Digital Packet Switched	GPRS	EDGE	
3G	Digital Packet Switched	UMTS	W-CDMA	CDMA2000
4G	Digital Broadband	802.11ac / LTE-A		

Wireless Today - Progress

		Data Rate
1G		9.6 Kbps to 14.4 Kbps
2G	D-AMPS	9.6 Kbps to 14.4 Kbps
	GSM	9.6 Kbps to 14.4 Kbps
	IS95A	9.6 Kbps to 14.4 Kbps
	IS95B	115 Kbps
2.5G		56 Kbps to 144 Kbps
3G	UMTS	2+ Mbps, up to 384 Kbps
	WCDMA	384 Kbps (wide area access), 2 Mbps (local area access)
	CDMA2000	614 Kbps

614 Kbps is nothing…

We want 100+ Megas and Gigas

3.5G HSPA+ 22 Mbps (uplink)

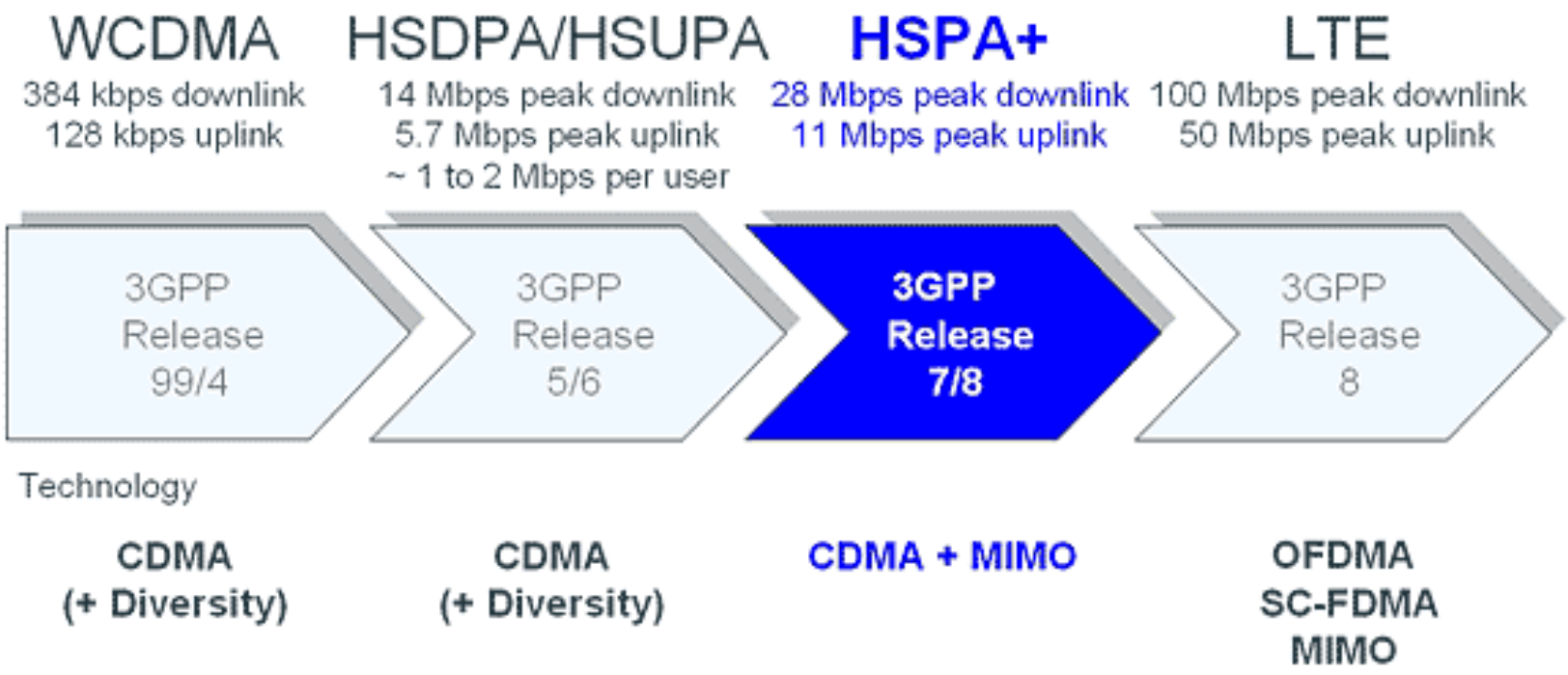
		Frequency	Carrier
1G		800 MHz	30 kHz
2G	D-AMPS	800 MHz or 1.9 GHz	30 kHz
	GSM	800 MHz or 1.9 GHz	200 kHz
	IS95A/B	800 MHz or 1.9 GHz	1.25 MHz
2.5G		800 MHz or 1.9 GHz	200 kHz
3G	UMTS	2 GHz	5 MHz
	WCDMA	2 GHz	5 MHz
	CDMA2000	2 GHz	1.25 MHz / 3.75 MHz
4G		In Development	In Development

800 – 2G Hz

range

Wireless Today - Progress

- Wireless makes progress via steps..

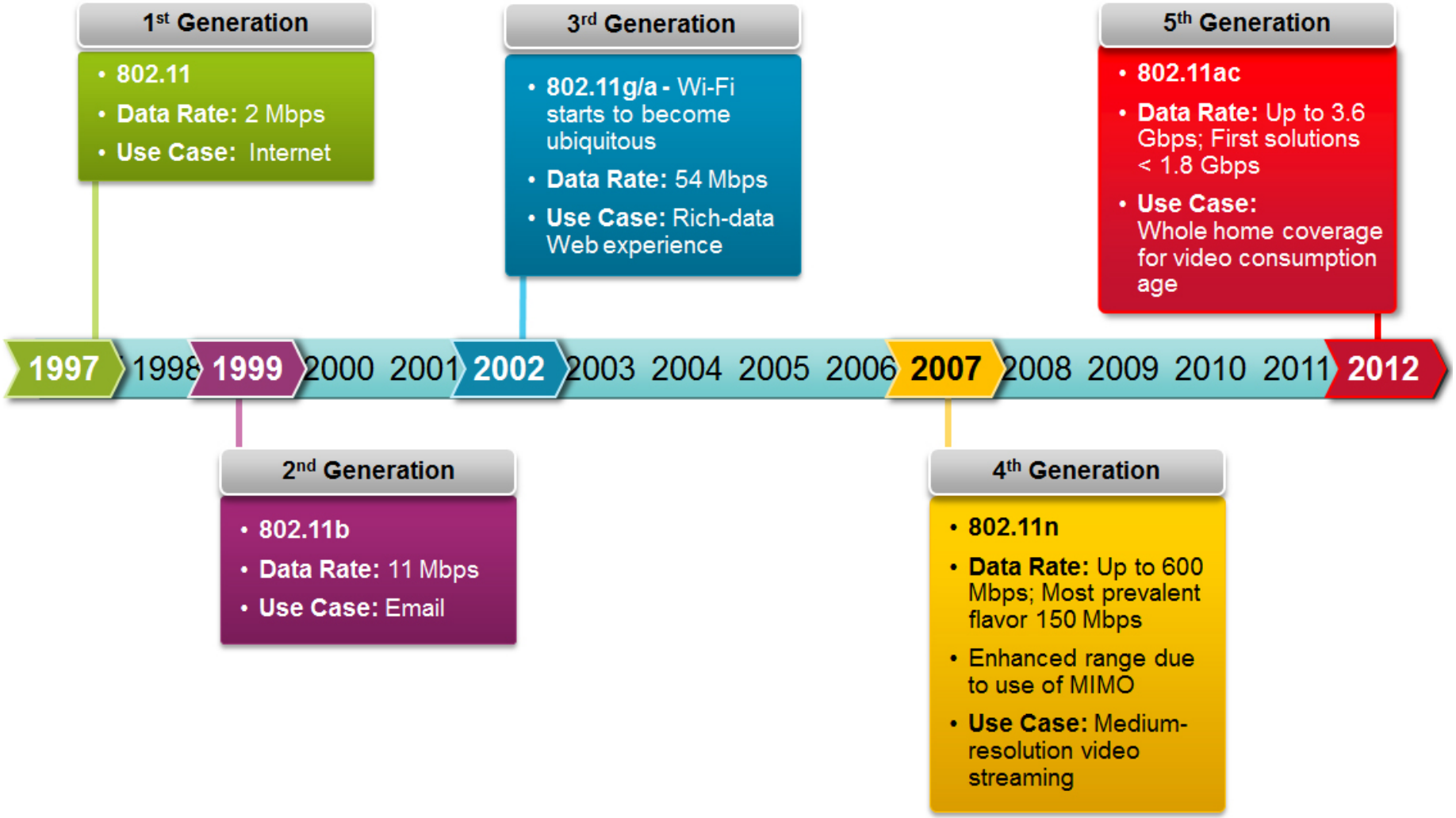


Wireless Today - Progress

The evolution of mobile standards

Mobile standards	3GPP		Qualcomm	China	IEEE
Carriers using:	AT&T and T-Mobile US, majority of global carriers		Sprint, Verizon Wireless	China Mobile	Sprint
2G: digital + data services	GSM: 2G		CDMAOne		
	GPRS: 2.5G				
	EDGE: 2.75G				
3G: at least 200 kbps iPhone 4 currently delivers up to 7.2Mbps down, 5.8Mbps up	Release 4	UMTS 3G	CDMA2000 EVDO rev 0	TD-SCDMA (up to 2Mbps)	
	Release 5	HSDPA 3.5G (to 21Mbps down)	CDMA2000 EVDO rev A (up to 3.1Mbps down, 1.8 up)		
	Release 6	HSUPA 3.5G (to 5.8Mbps up)	EVDO Rev C / Ultra Mobile Broadband Canceled: Sprint moving to WiMAX, Verizon moving to 3GPP LTE		Mobile WiMAX 3.9G (4 Mbps cap on EVO "4G")
	Release 7	HSPA+ 3.5G			
	Release 8/9	LTE 3.9G			
4G: at least 100 Mbps, IP-based	Release 10	LTE Advanced		TD-LTE	WiMAX 4G

Wireless Today - WiFi Evolution



Wireless Today - iPhone madness…

								
	iPhone	**iPhone 3G**	**iPhone 3GS**	**iPhone 4**	**iPhone 4S**	**iPhone 5**	**iPhone 5c**	**iPhone 5s**
Code Name	M68	N82	N88	N90	N94	N41	N48	N51
Model Name	iPhone 1,1	iPhone 1,2	iPhone 2,1	iPhone 3,1	iPhone 4,1	iPhone 5,1	iPhone 5,3	iPhone 6,1
OS	iPhone OS 1.0	iPhone OS 2.0	iPhone OS 3.0	iOS 4	iOS 5	iOS 6	iOS 7	iOS 7
Screen Size	3.5-inch 480x320 at 163ppi	3.5-inch 480x320 at 163ppi	3.5-inch 480x320 at 163ppi	3.5-inch IPS 960x640 at 326ppi	3.5-inch IPS 960x640 at 326ppi	4-inch 1136x640 in-cell IPS LCD at 326ppi	4-inch 1136x640 in-cell IPS LCD at 326ppi	4-inch 1136x640 in-cell IPS LCD at 326ppi
System-on-chip	Samsung S5L8900	Samsung S5L8900	Samsung APL0298C05	Apple A4	Apple A5	Apple A6	Apple A6	64-bit Apple A7, M7 motion c-processor
CPU	ARM 1176JZ(F)-S	ARM 1176JZ(F)-S	600MHz ARM Cortex A8	800MHz ARM Cortex A8	800MHz dual-core ARM Cortex A9	1.3GHz dual-core Swift (ARM v7s)	1.3GHz dual-core Swift (ARM v7s)	1.3GHz dual-core Cyclone (ARM v8)
GPU	Power VR MBX Lite 3D	Power VR MBX Lite 3D	PowerVR SGX535	PowerVR SGX535	PowerVR dual-core SGX543MP4	PowerVR triple-core SGX543MP3	PowerVR triple-core SGX543MP3	PowerVR G6430
RAM	128MB	128MB	256MB	512MB	512MB	1GB	1GB	1GB DDR3
Storage	4GB/8GB (16GB later)	8GB/16GB	16GB/32GB	16GB/32GB	16GB/32GB/64GB	16GB/32GB/64GB	16GB/32GB	16GB/32GB/64GB
Top Data Speed	EDGE	3G 3.6	HSPA 7.2	HSPA 7.2	HSPA 14.4	LTE/DC-HSPA	LTE/DC-HSPA	LTE/DC-HSPA
SIM	Mini	Mini	Mini	Micro	Micro	Nano	Nano	Nano
Rear Camera	2MP	2MP	3MP/480p	5MP/720p, f2.8, 1.75*μ*	8MP/1080p, f2.4, BSI, 1.4*μ*	8MP/1080p, f2.4, BSI, 1.4*μ*	8MP/1080p, f2.4, BSI, 1.4*μ*	8MP/1080p, f2.2, BSI, 1.5*μ*
Front Camera	None	None	None	VGA	VGA	1.2MP/720p, BSI	1.2MP/720p, BSI	1.2MP/720p, BSI
Bluetooth	Bluetooth 2.0 + EDR	Bluetooth 2.0 + EDR	Bluetooth 2.1 + EDR	Bluetooth 2.1 + EDR	Bluetooth 4.0	Bluetooth 4.0	Bluetooth 4.0	Bluetooth 4.0
WiFi	802.11 b/g	802.11 b/g	802.11 b/g	802.11 b/g/n (2.4GHz)	802.11 b/g/n (2.4GHz)	802.11 b/g/n (2.4 and 5GHz)	802.11 b/g/n (2.4 and 5GHz)	802.11 b/g/n (2.4 and 5GHz)
GPS	None	aGPS	aGPS	aGPS	aGPS, GLONASS	aGPS, GLONASS	aGPS, GLONASS	aGPS, GLONASS
Sensors	Light, accelerometer, proximity	Light, accelerometer, proximity	Light, accelerometer, proximity, compass	Light, accelerometer, proximity, compass, gyroscope	Light, accelerometer, proximity, compass, gyroscope, infrared	Light, accelerometer, proximity, compass, gyroscope, infrared	Light, accelerometer, proximity, compass, gyroscope, infrared	Light, accelerometer, proximity, compass, gyroscope, infrared, fingerprint identity
Mic	Single	Single	Single	Dual	Dual	Triple	Triple	Triple
Connector	30-pin Dock	30-pin Dock	30-pin Dock	30-pin Dock	30-pin Dock	Lightning	Lightning	Lightning
Size	115 x 61 x 11.6 mm	115.5 x 61.8 x 12.3 mm	115.5 x 61.8 x 12.3 mm	115.2 x 58.6 x 9.3 mm	115.2 x 58.6 x 9.3 mm	123.8 x 58.6 x 7.6mm	124.4.8 x 59.2 x 8.97mm	123.8 x 58.6 x 7.6mm
Weight	135 g	133 g	135 g	137 g	140 g	112 g	132 g	112 g
Battery	1400 mAh	1150 mAh	1219 mAh	1420 mAh	1430 mAh	1440 mAh	1440 mAh	TBD

Wireless Today - 4G

- LTE Subscribers over 100 Million
- 4G – IMT-A (100Mbps hi mob / 1G bps low mob)
  - 3GPP proposed LTE
  - IEEE 802.16e WiMax
  - IEEE WiFi 802.11ac (500 Mbps)

Data speeds of LTE

	LTE
Peak download	100 Mbit/s
Peak upload	50 Mbit/s

LTE – 3GPP R8

Data speeds of LTE Advanced

	LTE Advanced
Peak download	1 Gbit/s
Peak upload	500 Mbit/s

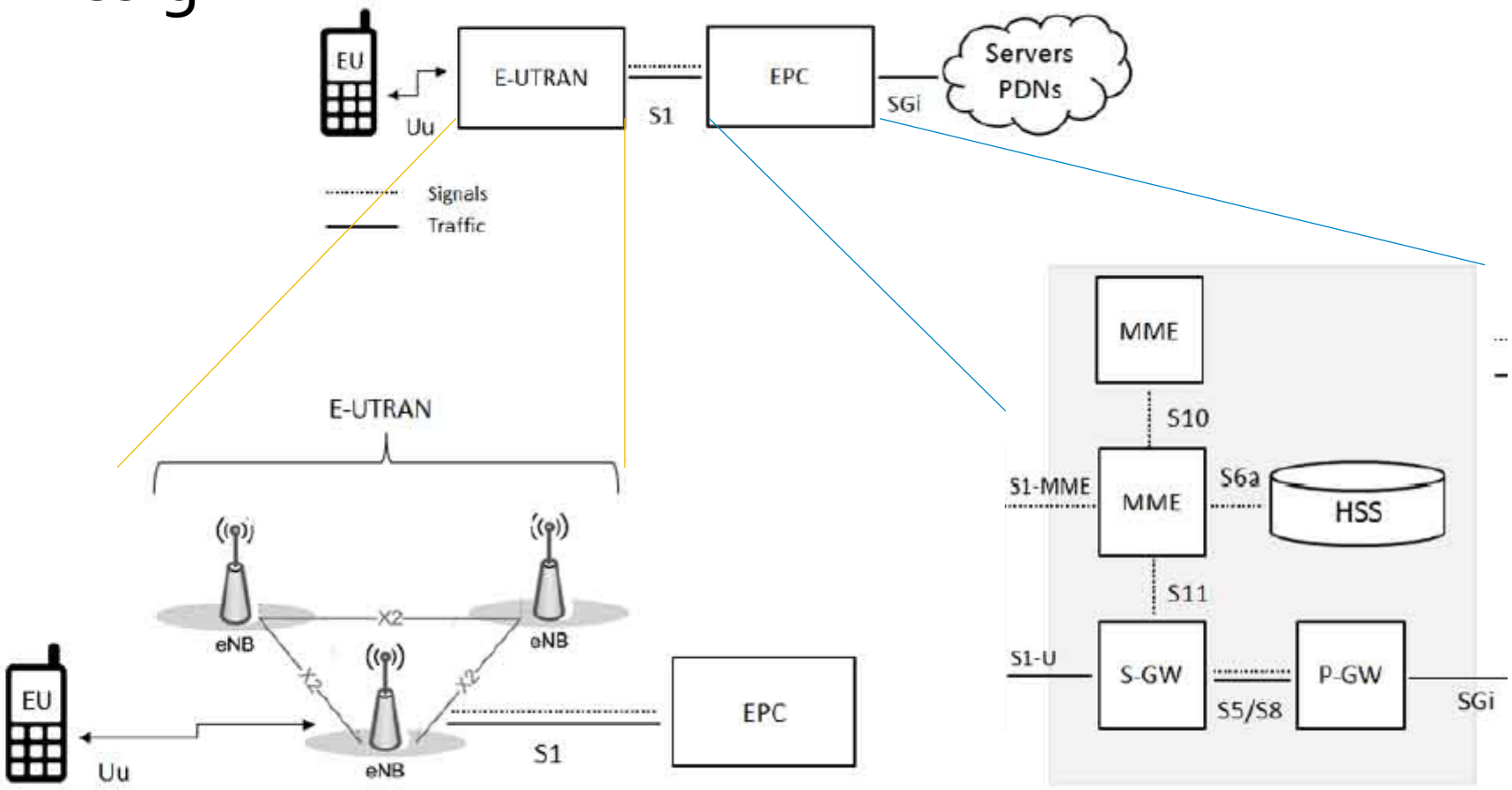
Data speeds of WiMAX

	WiMAX
Peak download	128 Mbit/s
Peak upload	56 Mbit/s

LTE- A 3GPP R10 = x10 LTE

Wireless Today: LTE – Architecture Advances

- Design



Wireless Today - LTE

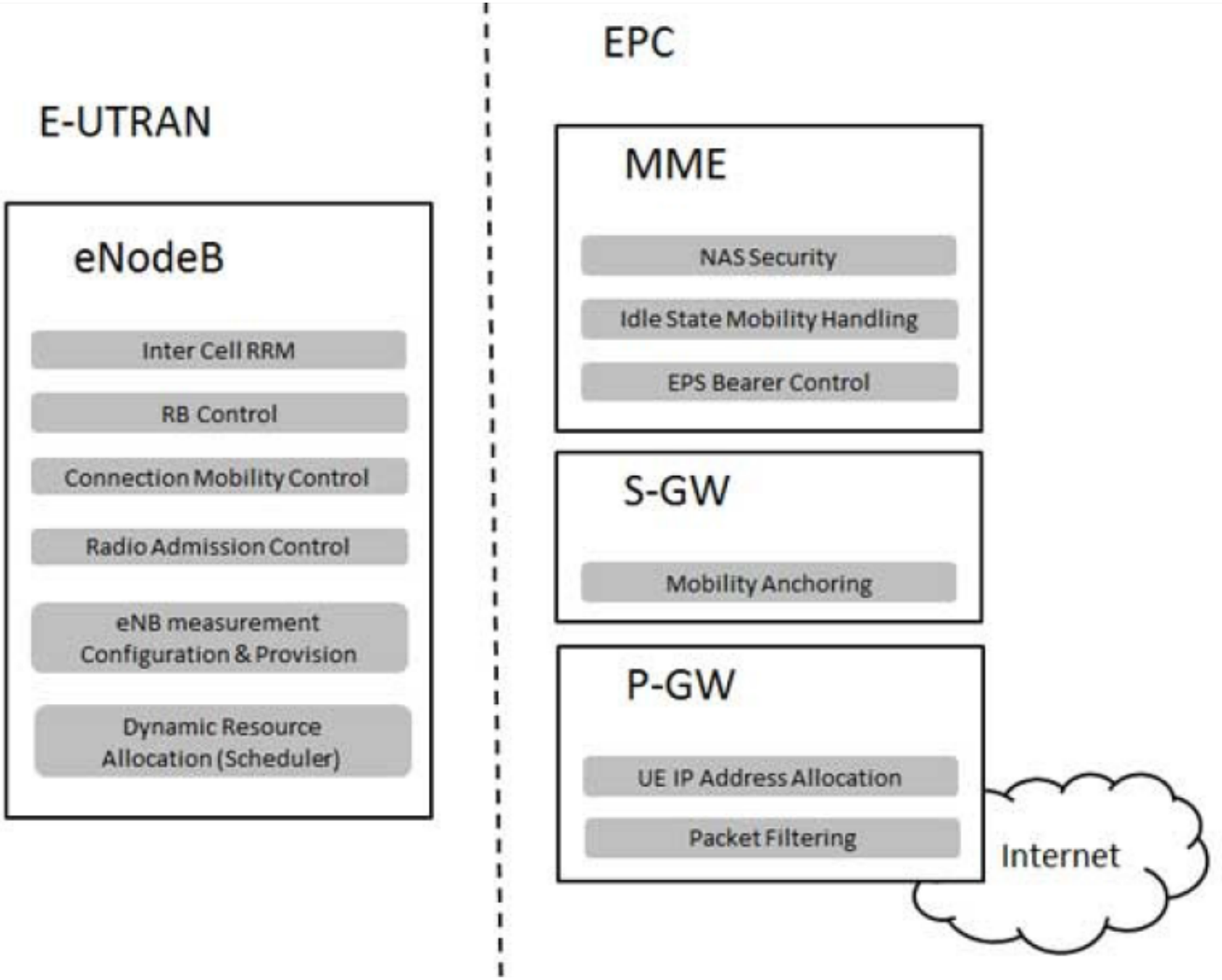
- Functions

LTE is:

All IP
Uses OFDM
Uses MIMO
SAE is EPC

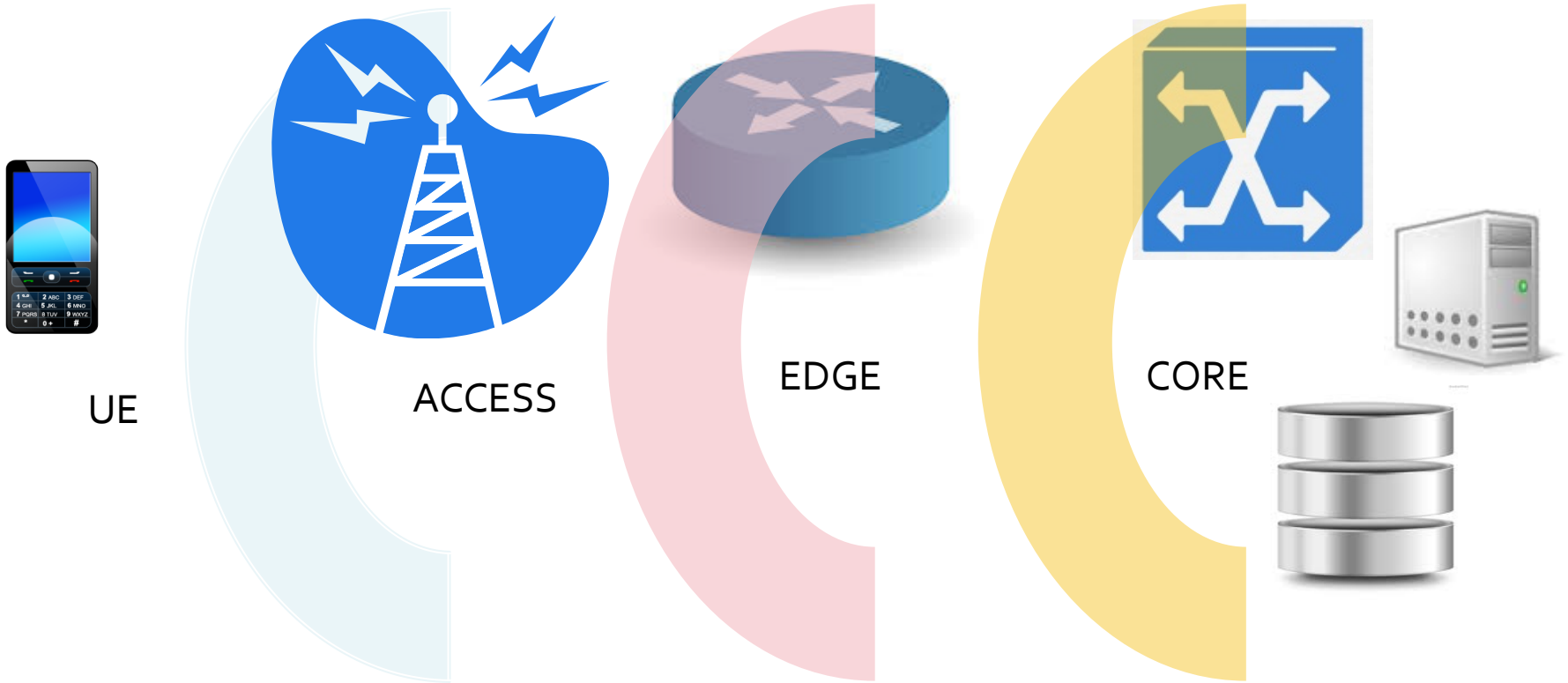
RNC + RRM
= now eNB

VoLTE uses
IMS



Wireless Today - Advances

- Architecture Evolution



Wireless Today - Functions

New
Stuff here !!

All-IP
Management

Mobility
Management
- Roaming
- Handoffs

Billing & Charging
Management

Connection
Management

Location
Management

Security (AAA)
Management

Wireless Challenges: 5G

- EU FP7 METIS 2020
- UK 5G Research Center
- SAMSUNG 5G
- No 5G standards yet..

Still

- Radio link technology
- Radio access technology

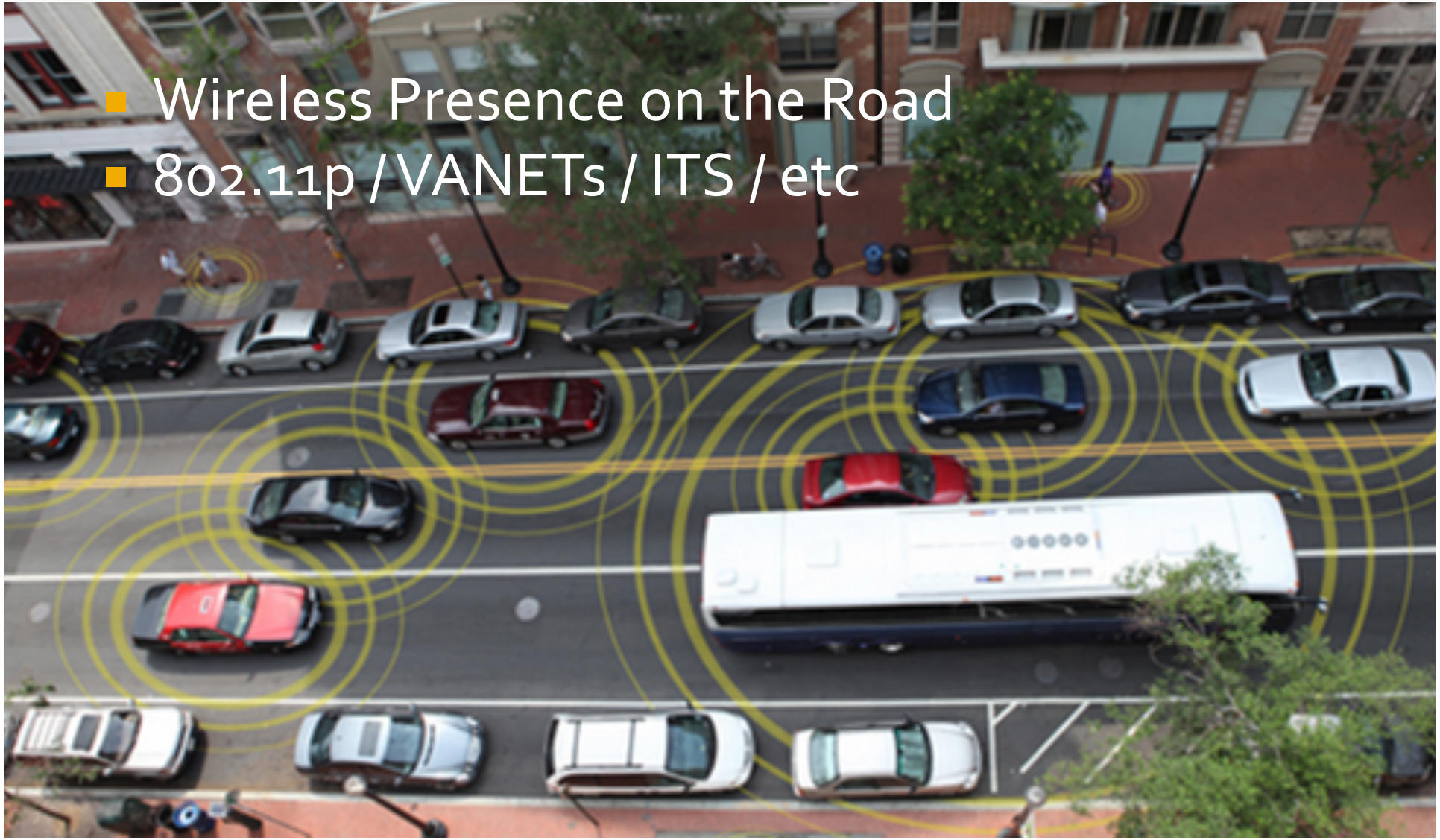
And

- 1000x traffic increase
- IoT (connected devices)
- WoT (wireless of things)
- 10 Gbps
- Faster (lower latency)
- Cloud-based RAN
- Core virtualization
- Nano-cells….
- Green radios…

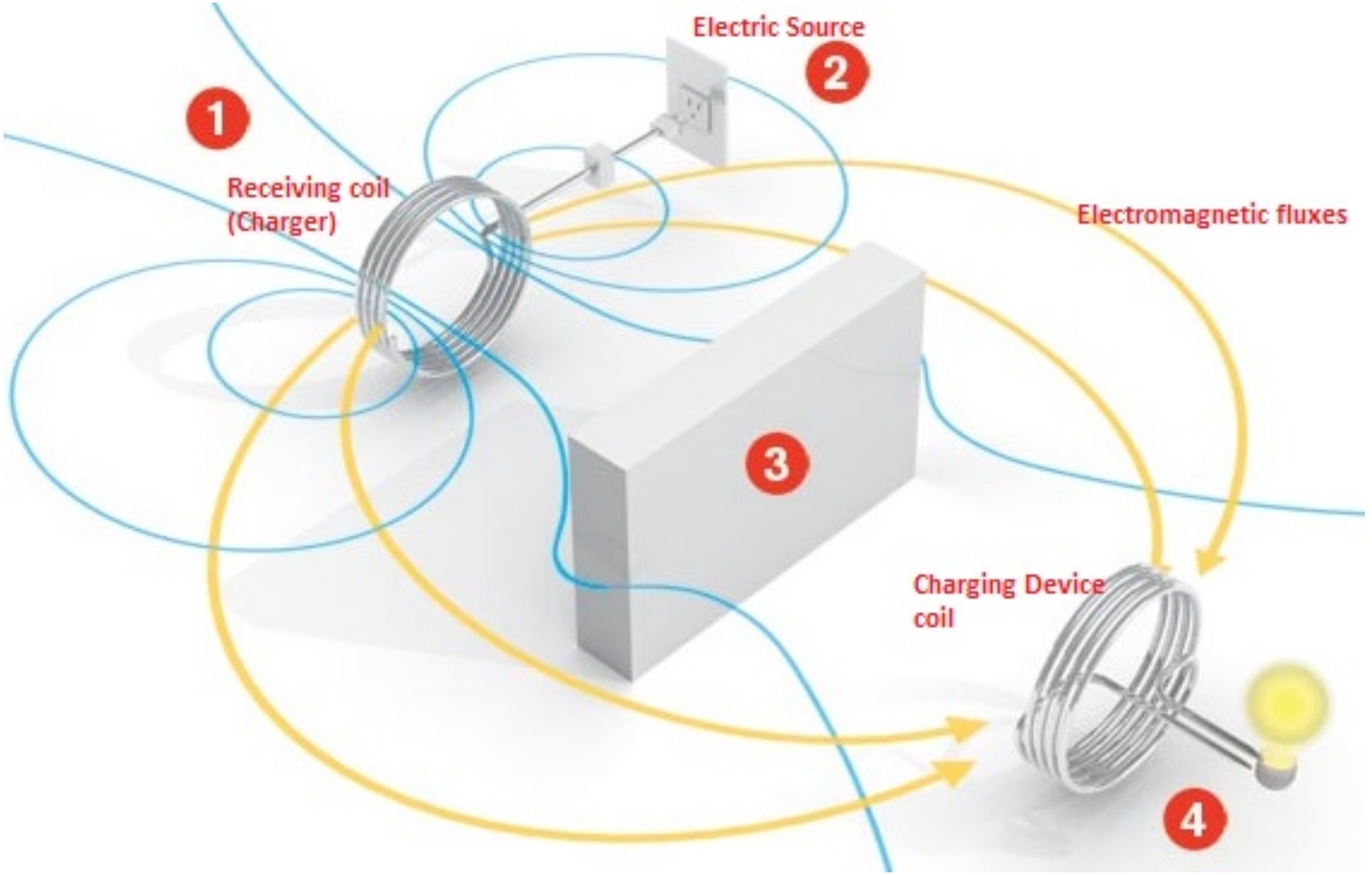
Wireless Challenges: Mobile Software

- Mobile Applications
- iOS
- Android
- IDE
  - 1000s of mobile service applications can be built for mobile devices
  - Almost anyone can write one…

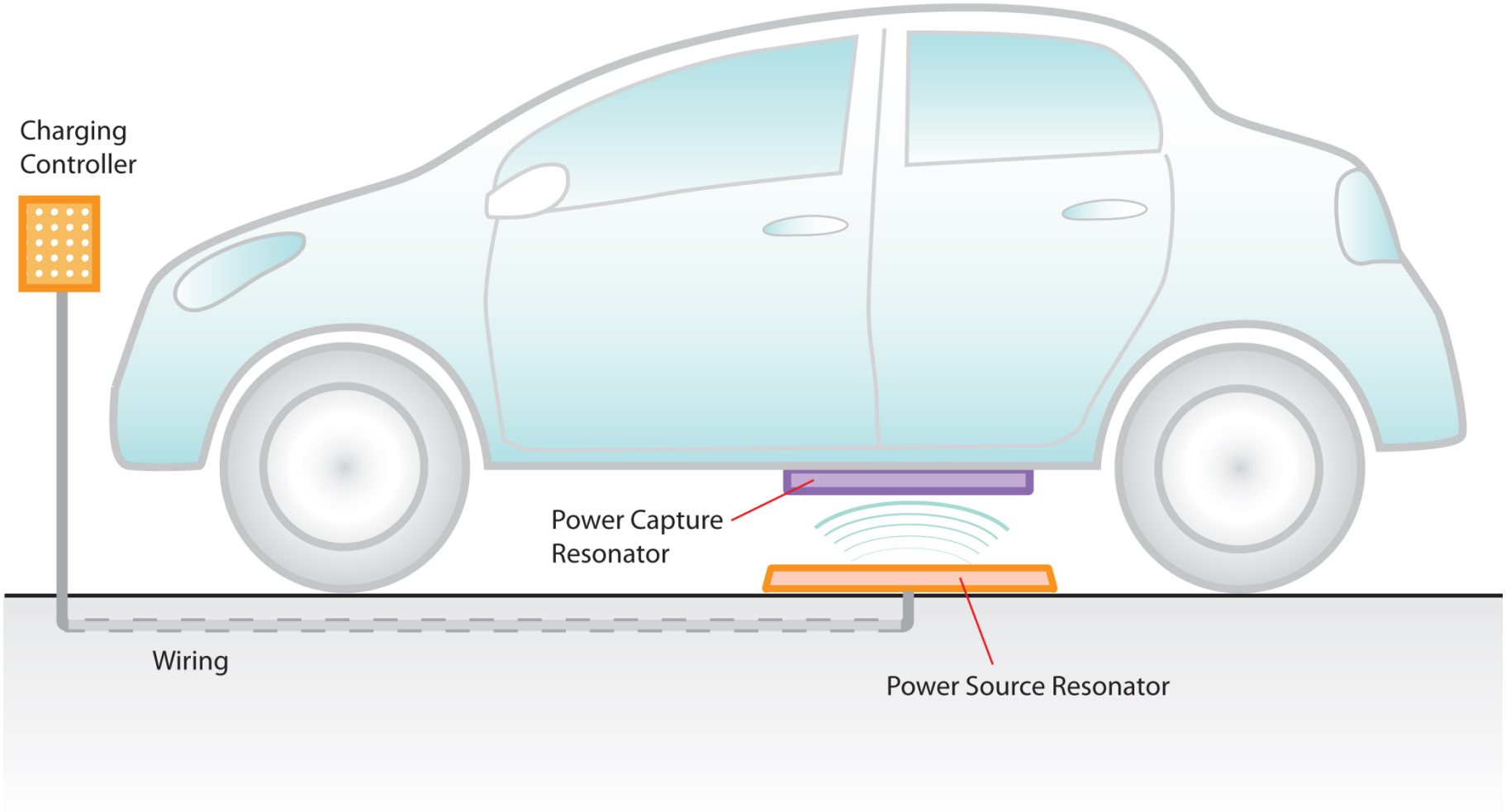
Wireless Challenge: Telematics Advances



Wireless Challenges – RF Charging

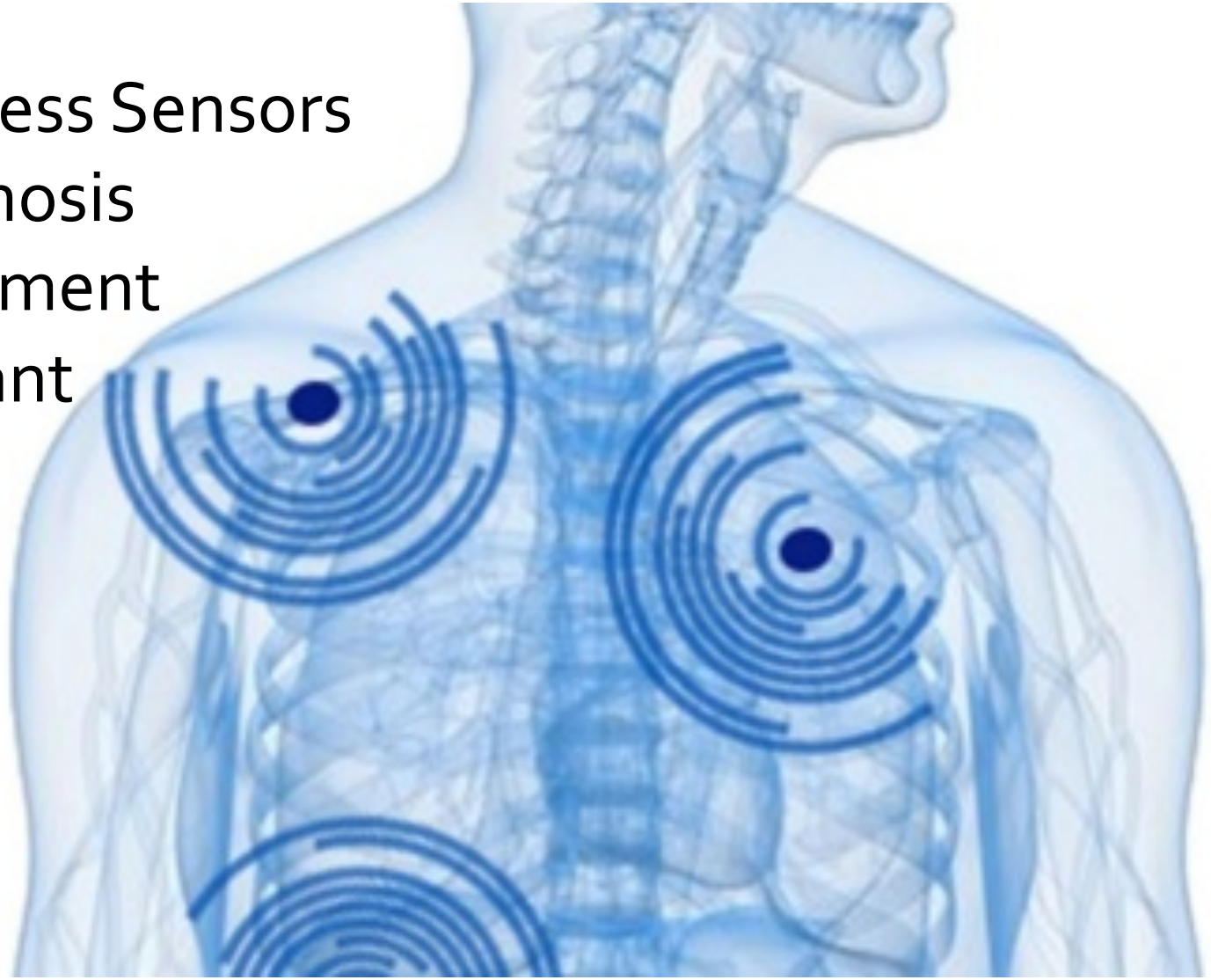


Wireless Challenges - Charging



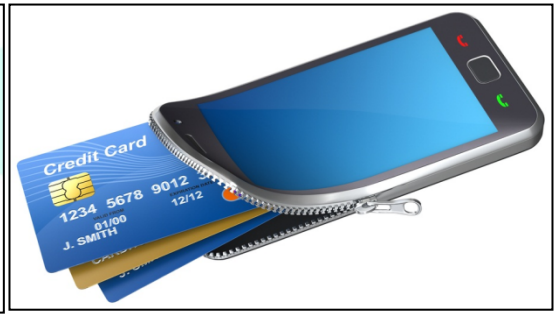
Wireless Challenges - Health

- Wireless Sensors
- Diagnosis
- Treatment
- Implant



Wireless Challenges: $$ / Wallet

- Wireless E-Commerce
  - Forget about AMAZON, eBAY, PAYPAL,…
  - Try immersive experiences
  - Try wireless retail, mobile banking, etc.
  - Trade wirelessly..
  - Pay wirelessly..



Wireless Challenge: APPLE's WISH

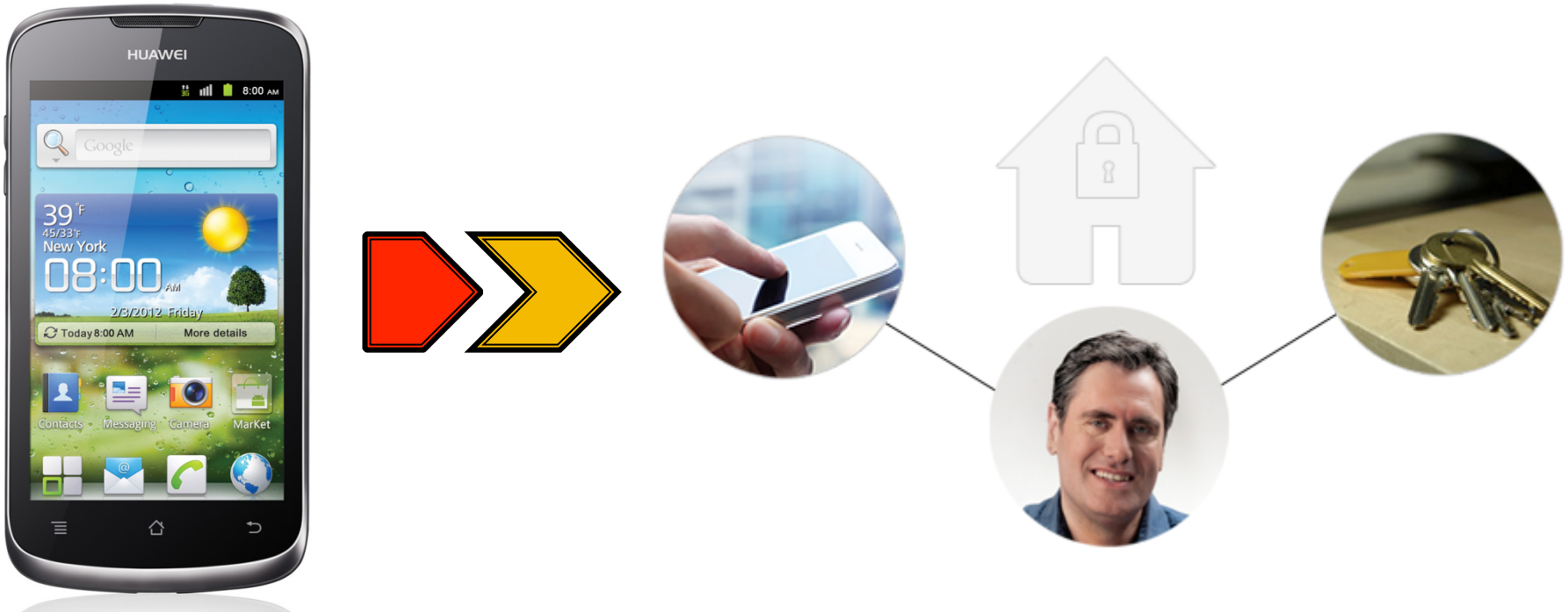
- APPLE would like iPhone be "**core**" of every car, much like the "**core**" that powers IRON MAN

Mobile Phone – Mobile Device

- Transformation

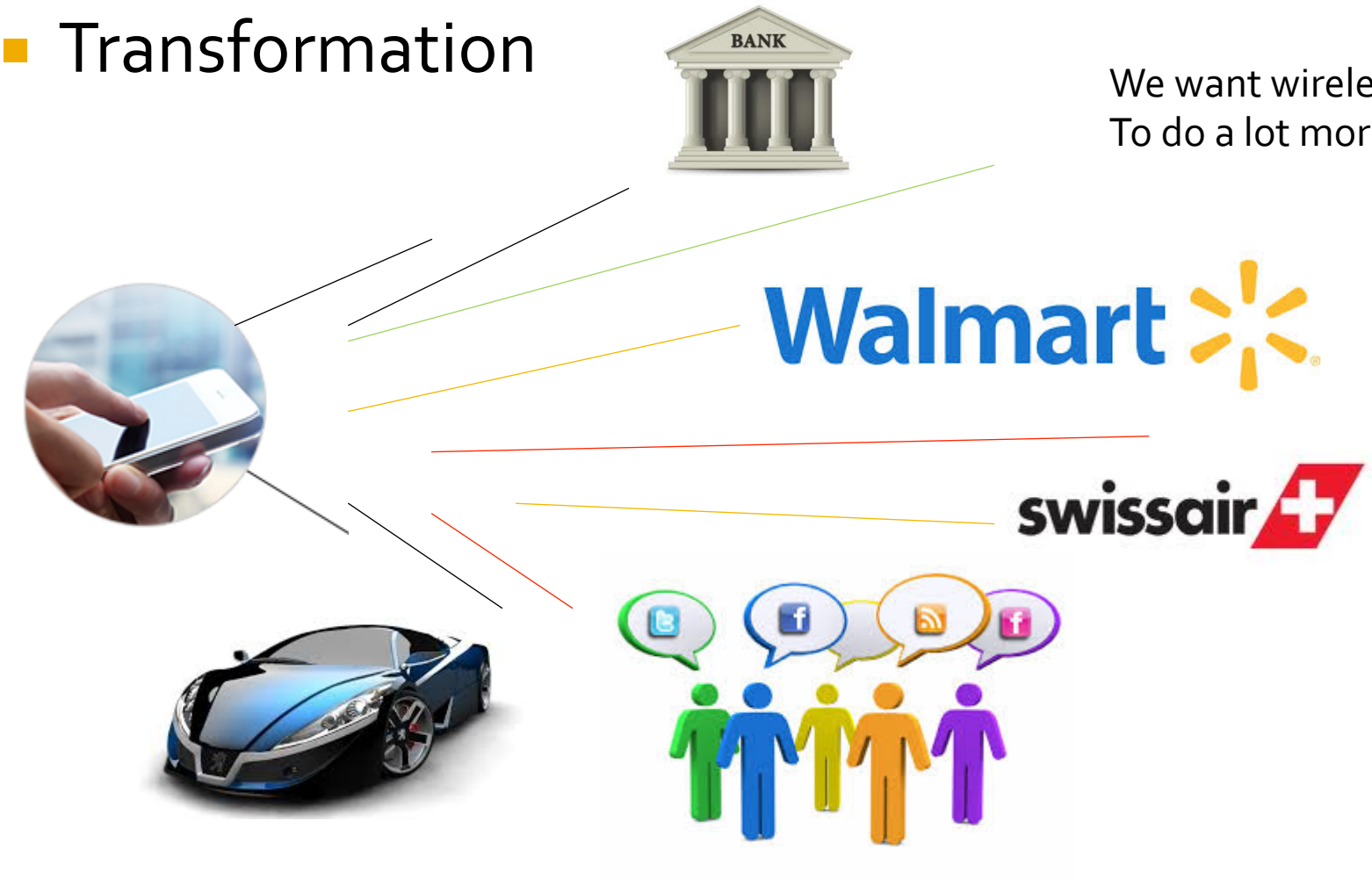
Mobile Device – Mobile Controller

- Transformation



Mobile Controller – Mobile Life

- Transformation



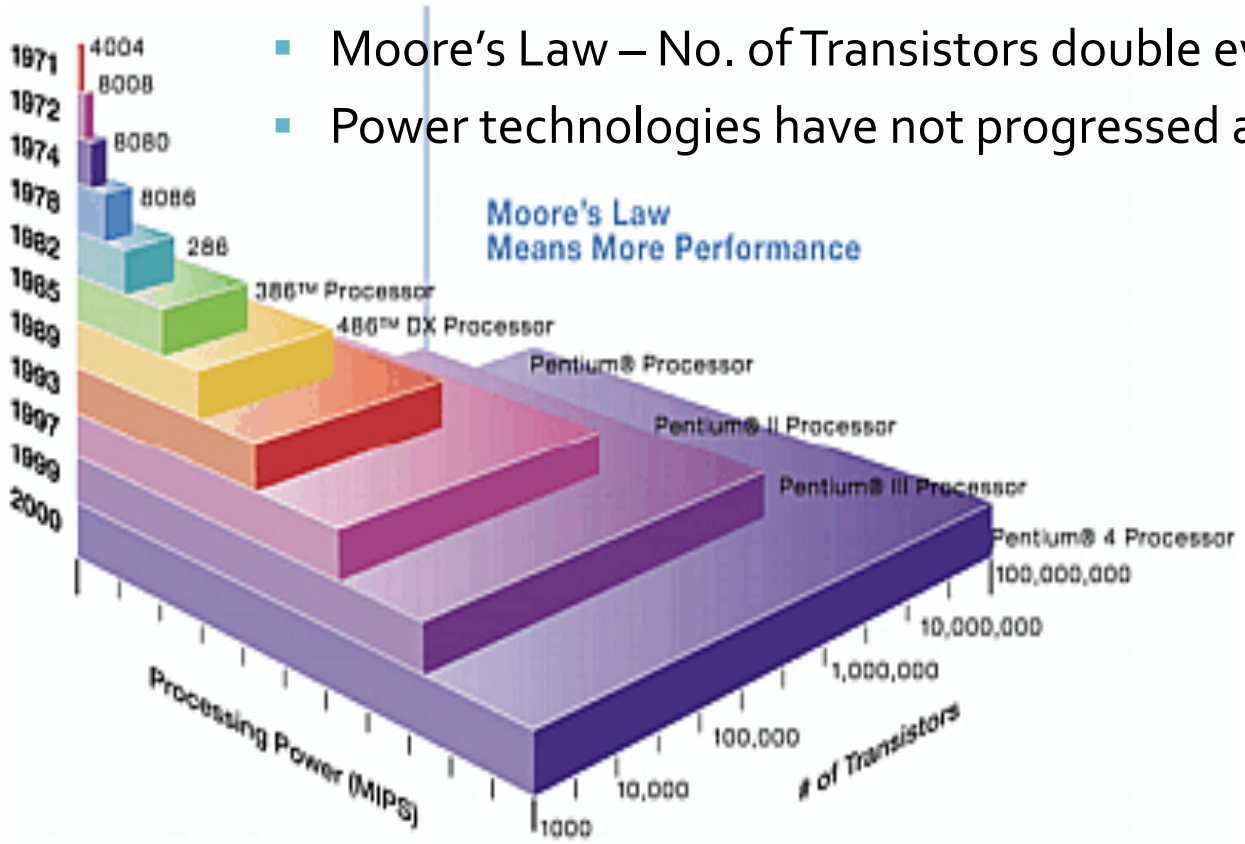
Mobile Life - Enabler

- Transformation

Our quality of life and well being depends on Wireless !!

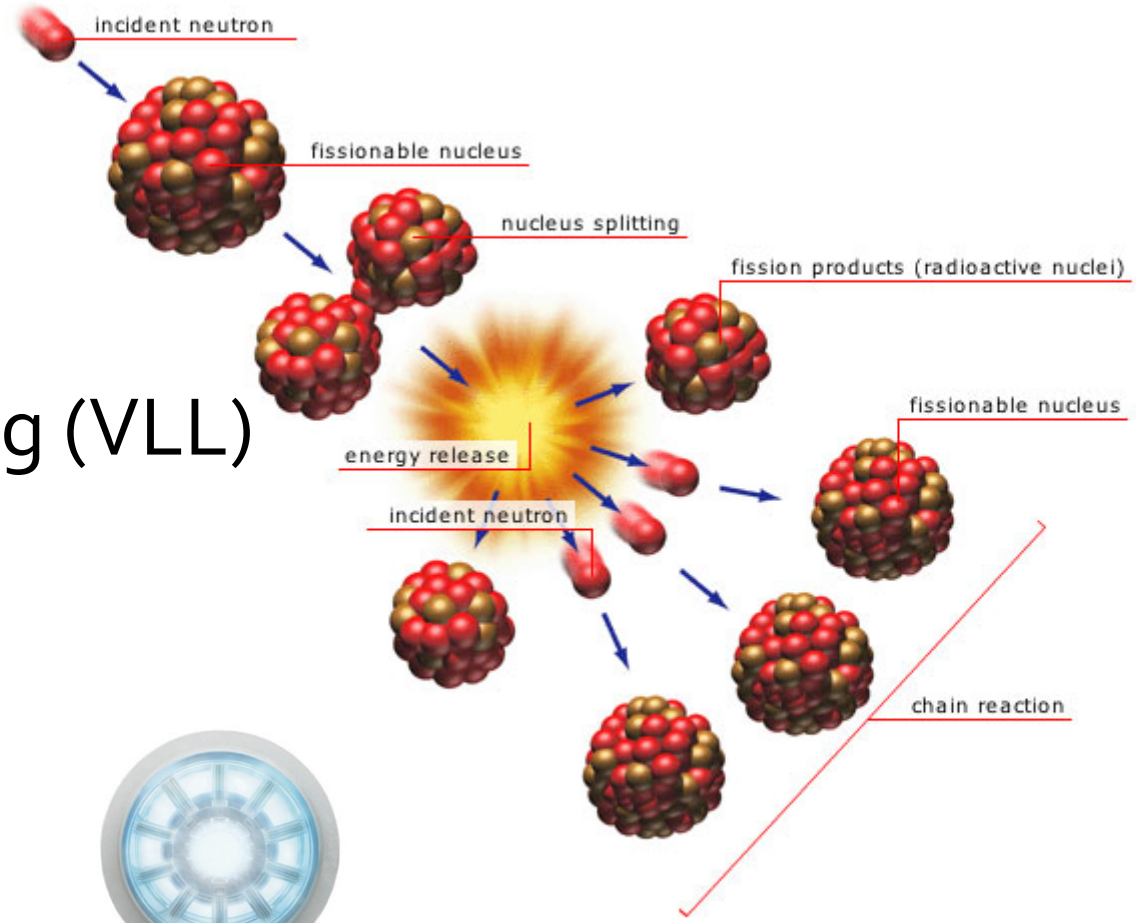
Wireless Challenge - Power

- No Power No Talk !!
- 2004 – I advocate SAMSUNG to build VLL mobile devices
  - Moore's Law – No. of Transistors double every 2 years or so
  - Power technologies have not progressed as fast!!



Wireless Challenges - Power

- Power creation
- Charging
  - RF
  - Electrical
- Very Long Lasting (VLL)
  - Battery
  - Fuel
  - Particle…
  - Cycle



Wireless Challenges: FF

- Form Factor
  - What size is good?

- Function per inch
- Size one can carry

Wireless Challenges: Display

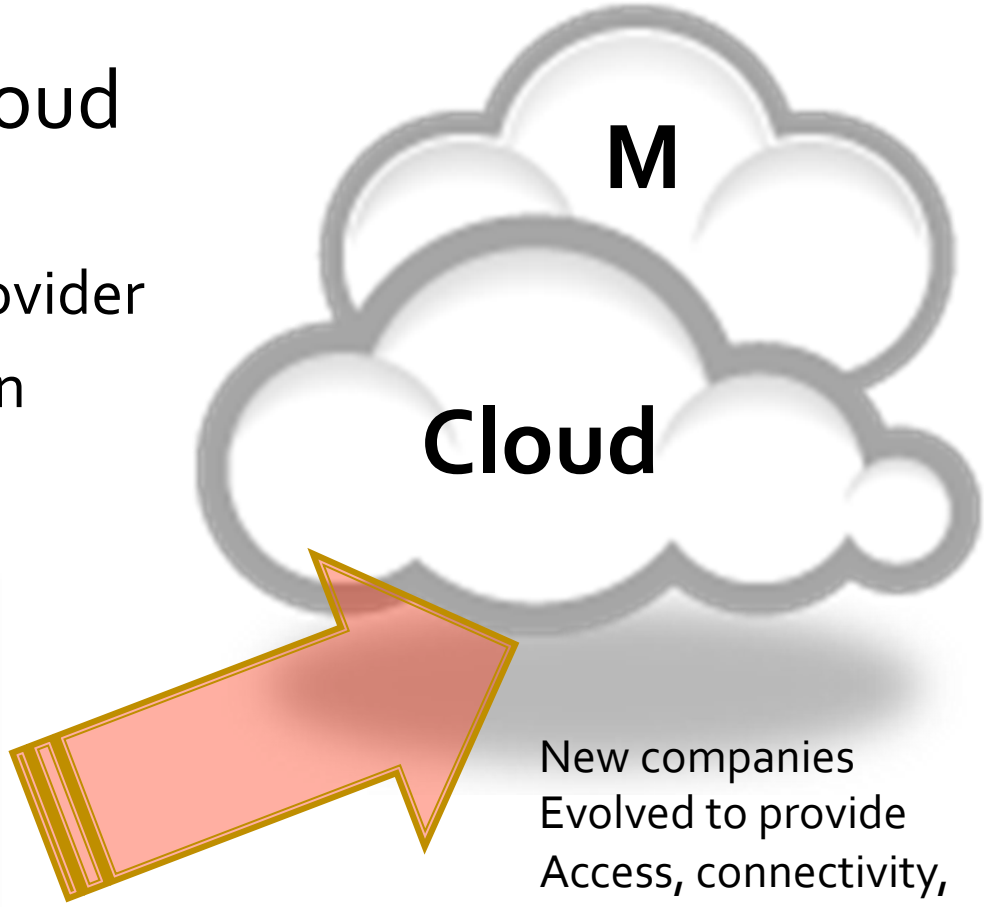
- Display Technologies
  - 3D
  - Still display on a screen?
  - Display on air?
  - Can wireless signal ignite a display??

Wireless Challenges: UI & XP

- Cool user interfaces
  - Beyond keyboards
  - Beyond mouse
    - Touch screen
    - Eye focus
    - Voice command
    - Brain waves
    - Body movement
    - Heat
    - Wireless interaction
  - HDI – human device interaction

Wireless Challenges: M Cloud

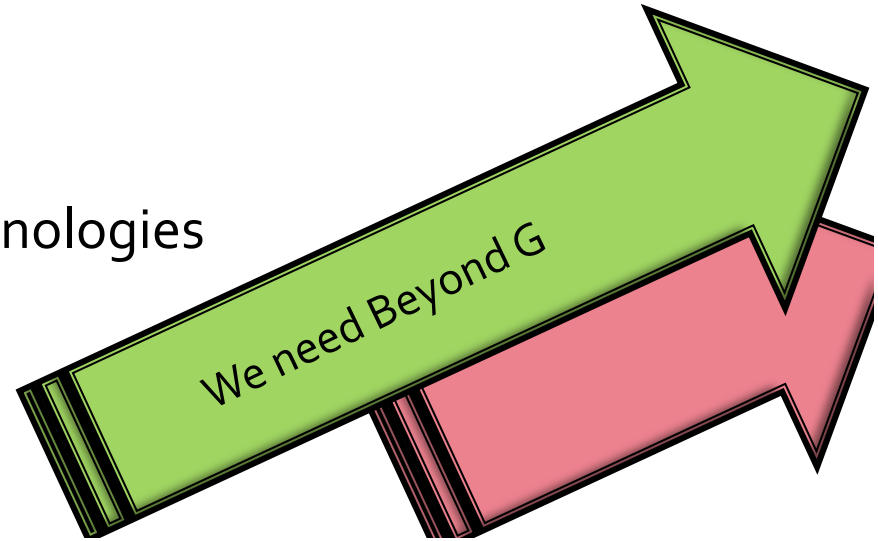
- Mobile (Wireless) Cloud
  - Pay as you good
  - Mobile Service Cloud Provider
  - M-Network Virtualization



New companies Evolved to provide Access, connectivity, Networks, and Services..

The ending of "G" ??

- **G for Generation**
- **Each generation adds value to its predecessor**
  - Architecture evolution
  - Higher throughput
  - Better link performance
  - Advance in modulation and antennas
  - Seamless handoff, vertical handoff, high speed handoffs
  - Multi-band multi-mode
  - Advance MAC protocols
  - All IP-based networks
  - Location & Positioning Technologies
  - Etc

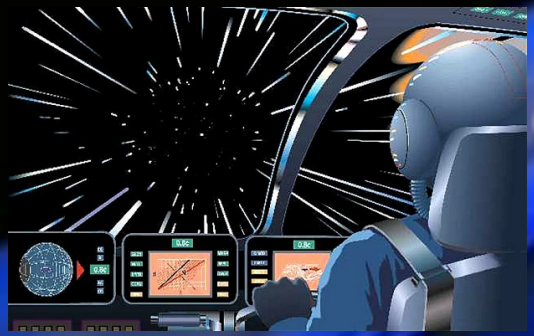


Wireless Beyond: What is next?

- Improvements in radio aspects may hit a limit
- Interoperability aspects will be fully resolved (WiFi/LTE/GSM/HSDPA/etc)
- Range extension and BS deployment fully resolved
- Wireless charging in action
- INTELLIGENCE in Wireless Device
- APPLICATIONS in Wireless Device
- BASICALLY,
  - What can you do with your wireless device?!
  - That would be the KEY to future of wireless !!!!

Wireless Beyond - Transporter

- Wireless is the “transporter” for our new generation
- It will transport “us” and our “data” to where “no man has been before” !!

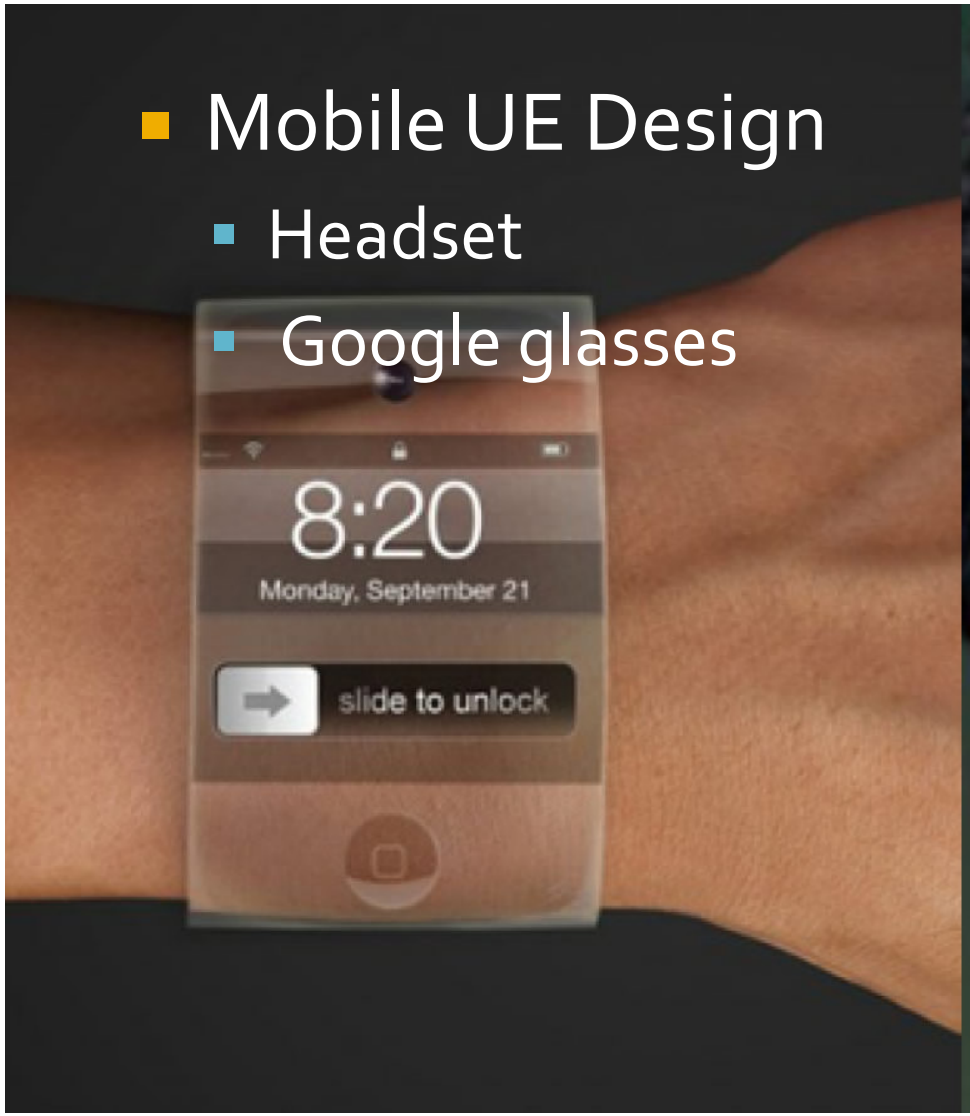


Wireless Beyond: UE

- UE Design
  - All-in-one
  - One-for-all
  - One-for-one
  - 1 gadget?
  - Multi-gadgets

Wireless Beyond

- Mobile UE Design
  - Headset
  - Google glasses



Wireless Beyond

- Mobile UE Design
  - Wrist
  - Arm

Wireless Beyond

- Mobile UE Design

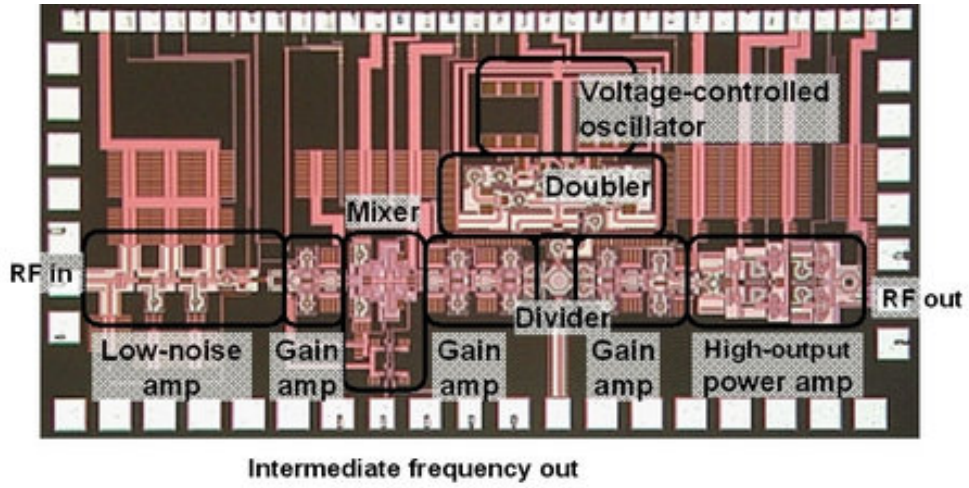
It's time!

Wireless Beyond

- Disaster is no fun !!
  - Wireless is not fearful of disaster
    - But we (humans) are!

Wireless Beyond

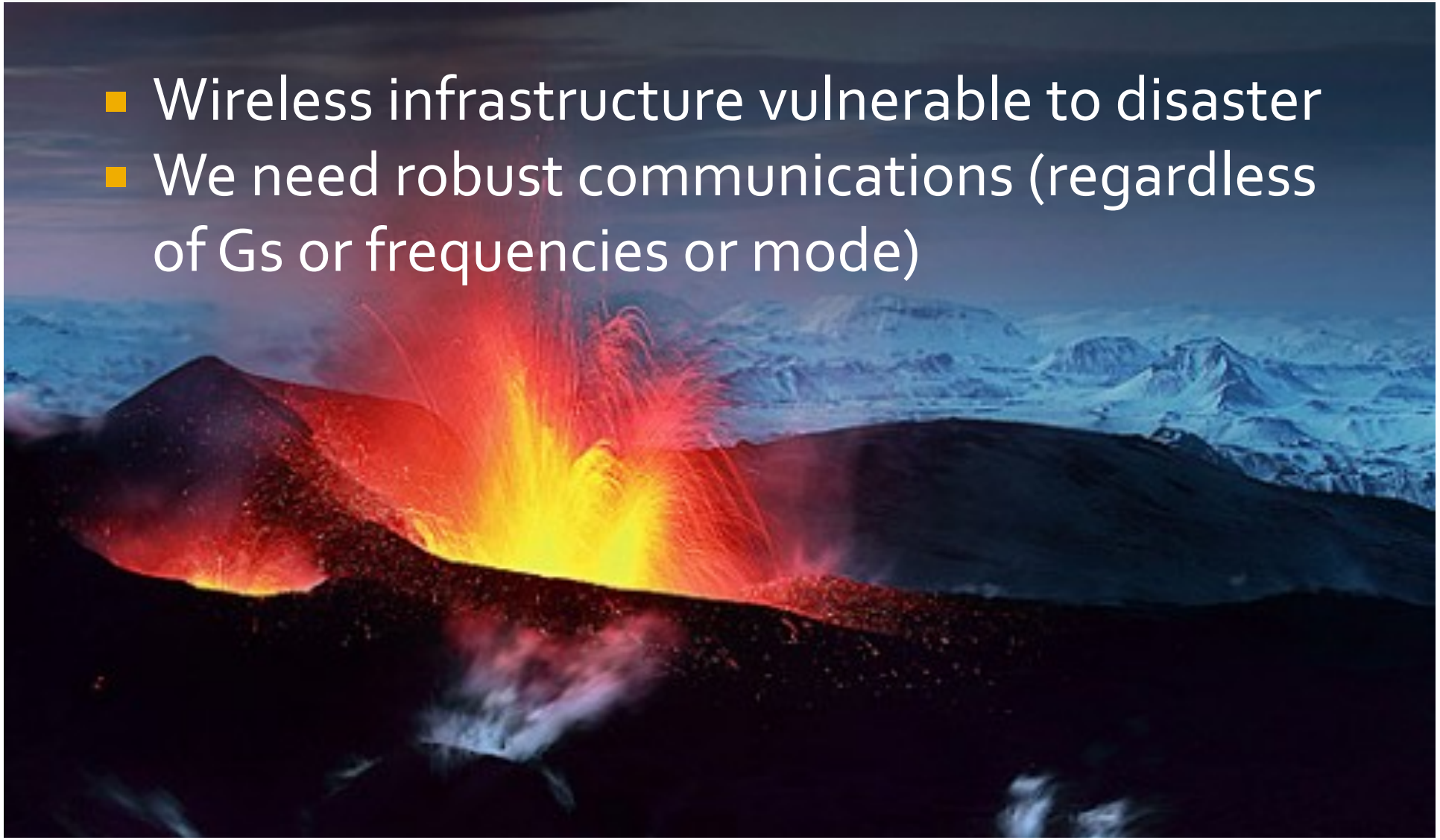
- Wireless Beyond - - This is not 5G !!
- Our innovation has been primarily bandwidth driven – radios, access, bits into signals, etc.
- Once we have "speed", we will want something else!!!



Wireless Beyond – Give me Cells

- **Give me more BW**
  - When I need it
  - Steering your beam + cell this way !!!
  - Dynamic cell placement
  - Cells on demand
- **BEFORE**
  - Cells & users are "Orthrogonal"
  - Cells did not follow users
  - Rather users must be on cell grid

Wireless Beyond



- Wireless infrastructure vulnerable to disaster
- We need robust communications (regardless of Gs or frequencies or mode)

Wireless Beyond - Fear

- Fear & Lonely
  - Humans are fearful to be alone
  - Wireless comms bridge this gap

Wireless Beyond

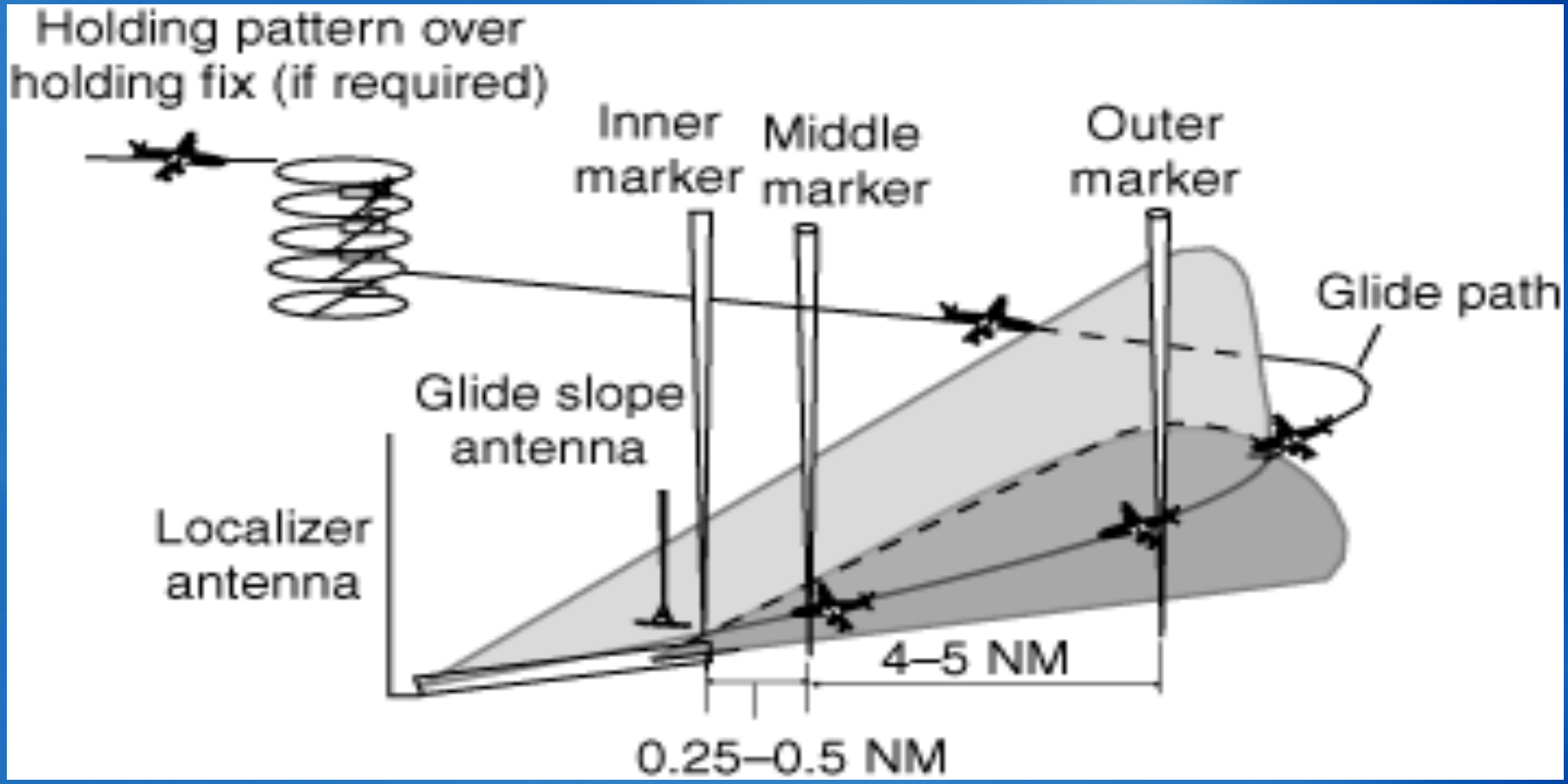
- **Empowered Individuals**
  - Wireless gadget/s empowered us
  - We don't want to dress up like IronMan.
- **One Device**
  - One main powerful device
  - Fulfill most of our needs
  - Empower us in many ways

Wireless Beyond

- Wireless Control – is crucial than ever

Wireless Beyond

- Wireless Control – is crucial than ever



Wireless Beyond

- Wireless Powered Social Networks
  - Your device is your key
  - Your device is your identity
  - Your device is your personality
  - Your device is the bridge to all your friends, social networks

Wireless Beyond – Grid Mergence

- Wireless Grid + Transportation Grid

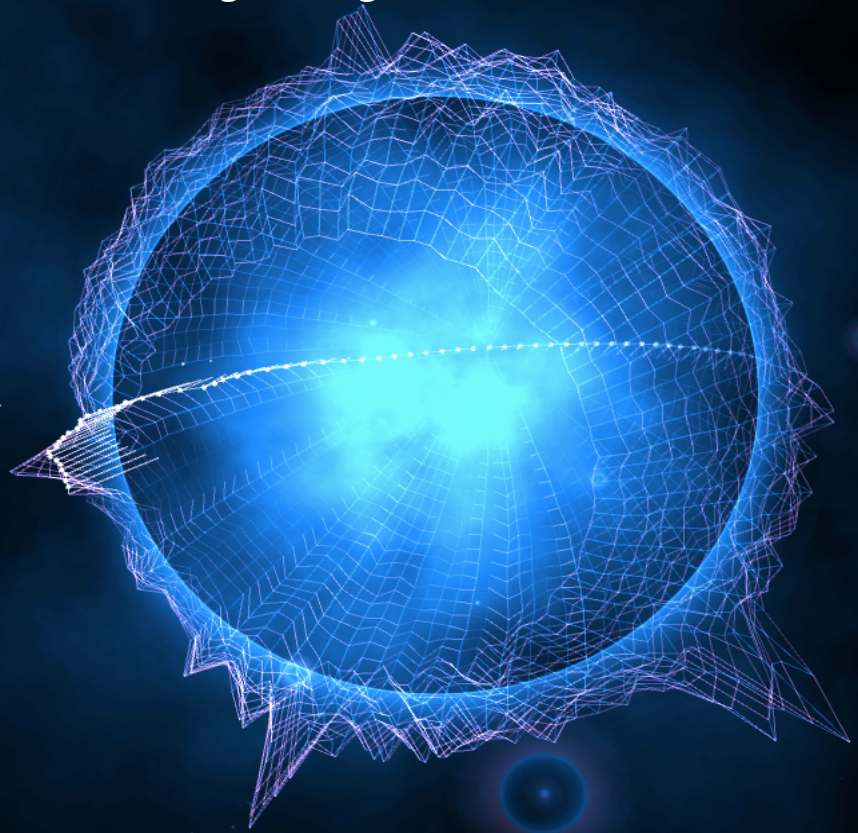
ITS – The comms-enabled Driver?

Move “indicators” outside the car!

- BASICALLY, WE WANT:
  - Cars that “talk”
  - Cars that “warn”
  - Cars that “sense”
  - Cars that “navigate”
  - Cars that “locate/find”
  - Cars that ..”you name it!”

Wireless Beyond

A world where wireless grids all blend together, seamlessly interwork, connect, empowering us…. One wireless grid of grids



Conclusion

- WIRELESS has made tremendous advances
- WIRELESS alone is incomplete
- WE need :
  - Truly wireless “sandwich”
  - Truly wireless transparency
  - COOL mobile applications
  - Ultimate wireless device
  - Empower the user!