



# **IMA Conference**

## **LTE vs. WiMAX: Complementing or Competing?**

### **Tel Aviv 29<sup>th</sup> Oct 2008**

**Technology Overview**  
**Key trends, facts and figures**

**Moray Rumney**  
**Lead Technologist**

# Moray Rumney

**Nationality** Scottish

**Education** BSc Electronics Heriot-Watt University, Edinburgh

**Company** Hewlett-Packard / Agilent – 24 years

**Experience** RF test equipment design and manufacture  
Focus on base station emulation

**Standards** ETSI since 1991 – Development of GSM  
3GPP RAN since 1999 – UMTS, HSPA, LTE

# Outline

Where is wireless at and where is it heading?

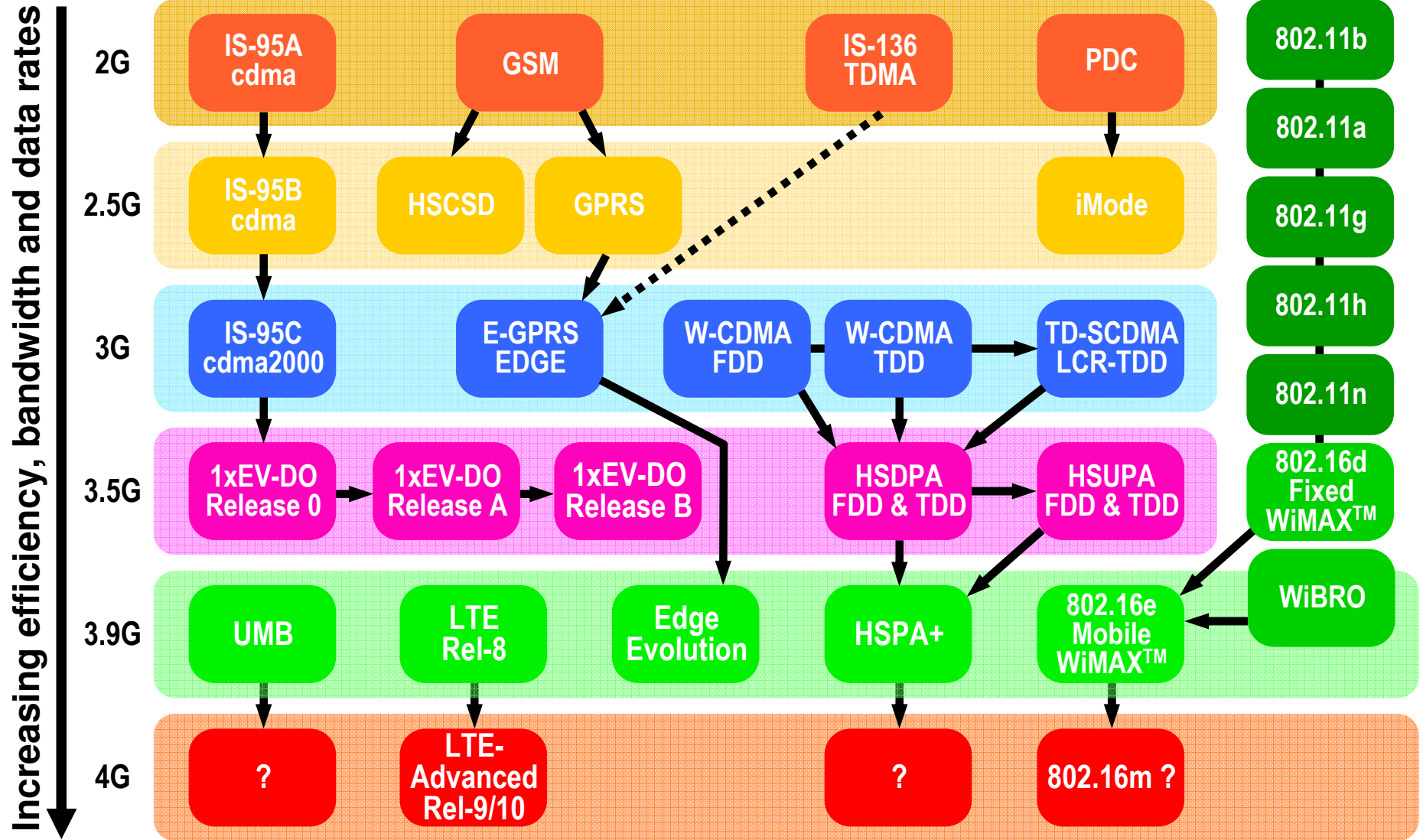
Examining the growing gap between peak rates and system capacity

Establishing the role of small cells in delivering mobile broadband

# Snapshot of attendees' mobile phone experiences

- Who's got a phone ?
- Who's got a camera phone ?
- Who has got a 3G phone ?
- Who regularly makes video calls ?
- Who surfs the mobile internet ?
- Who does mobile email ?
- Who's got a quad band GSM phone with GPRS and EGPRS, tri-band W-CDMA with HSDPA to 7.2 Mbps, diversity receiver with equalizer, MIMO and interference cancellation. Simultaneous voice and data, Push to talk. W-LAN for hotspot data and VoIP, Bluetooth, FM receiver for radio, Assisted GPS, two camera modules with autofocus 5 M-pixel camera with flash, zoom and video capability, TV out, Speakerphone with vibrate, MP3 and video player, PDA functionality, talking ringtones and voice recorder, SMS to speech, plus a removable memory stick for stirring coffee ?

# Wireless evolution 1990 - 2010



# Four key phases of commercial wireless development

## 1. Standardization The Committee Room



Where engineers consume lots of coffee while creating wireless law

## 2. Regulation The Test House



Where products are put on trial to prove their conformance

## 3. Physics Maxwell's Place

$$\begin{aligned}\nabla \times \mathbf{H} &= \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \mathbf{j} \\ \nabla \times \mathbf{E} &= -\frac{\partial \mathbf{H}}{\partial t} \\ \nabla \cdot \mathbf{H} &= 0 \\ \nabla \cdot \mathbf{E} &= \rho / \epsilon_0\end{aligned}$$

And then there was light...

Simulations do not apply!

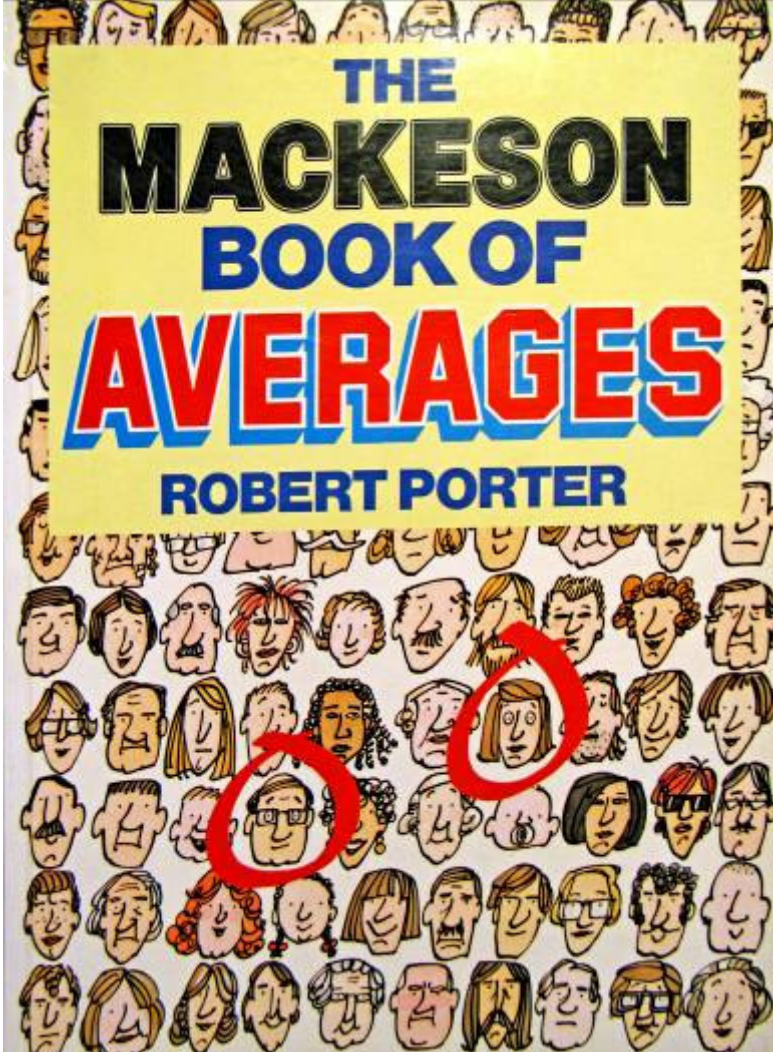
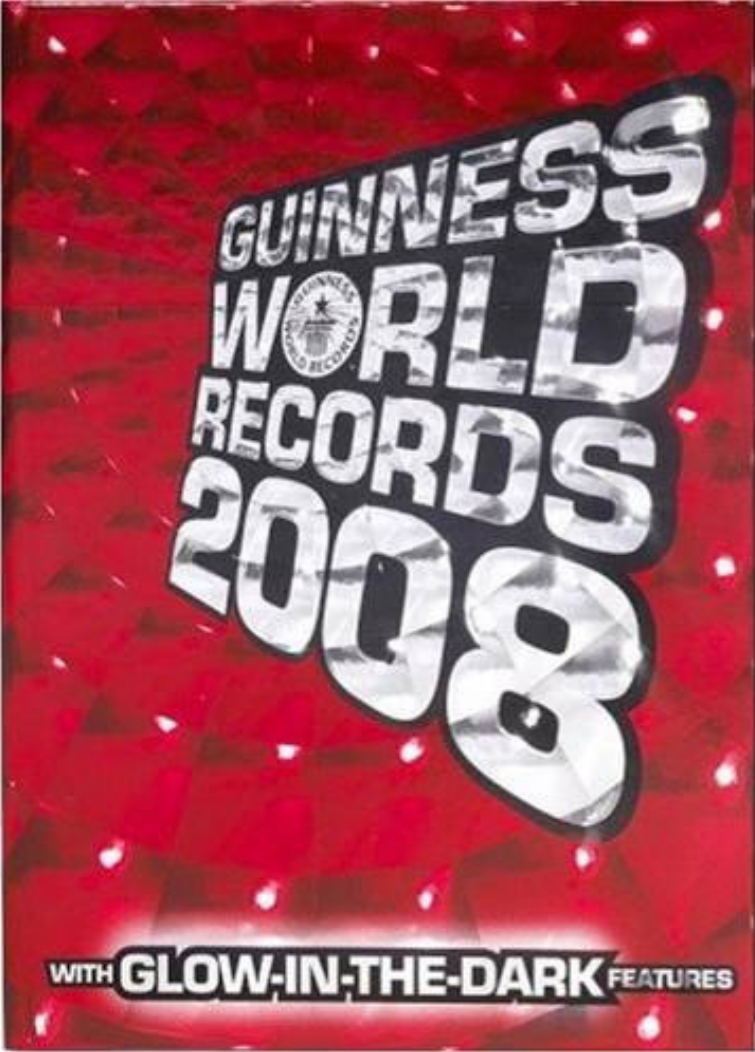
## 4. Commerce The Shopping Mall



Where commercial law determines whether anyone actually buys it

Just because the industry invents a new standard does not mean success is guaranteed. What determines commercial success?

# Peak vs. Average



# Quiz #1

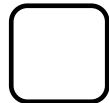
From press release announcing WiMAX adopted as IMT-2000 standard

[http://biz.yahoo.com/ap/071019/un\\_wimax.html?.v=1](http://biz.yahoo.com/ap/071019/un_wimax.html?.v=1)

“WiMAX™ is capable of delivering wireless broadband connections at speeds of 70 megabits per second or more across an area of up to 40 miles. It's faster than many fixed-line broadband connections today, which typically offer speeds of around 2 megabits per second.”



True



False

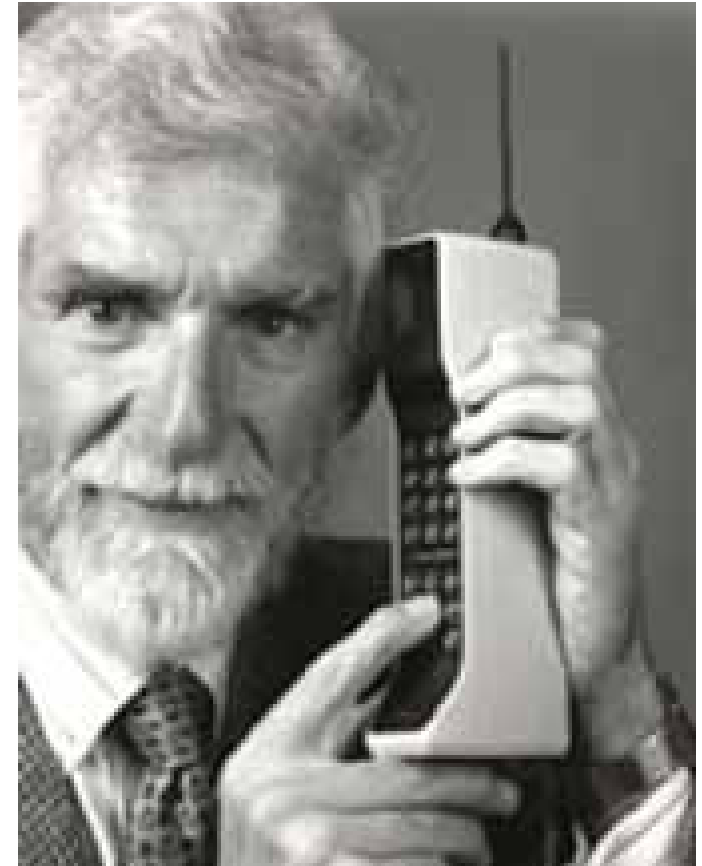
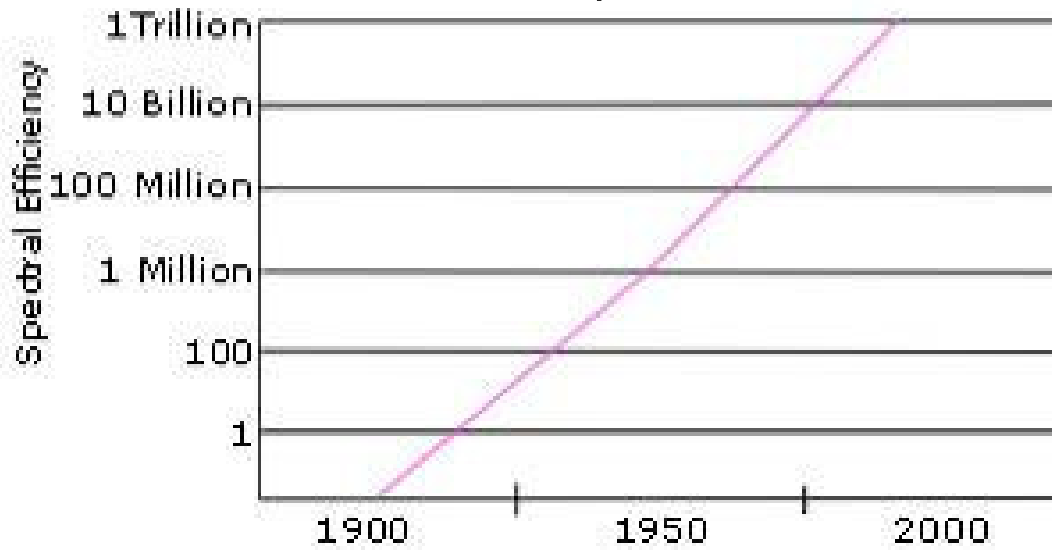
100% true but incomplete – The future is about data densities and the above is true for one user in an isolated (hotpot) cell

# Capacity growth - Cooper's law

Dr. Martin Cooper of Motorola - "father" of the modern mobile phone - has observed:

*The number of simultaneous voice and data connections has doubled every 2.5 years since wireless began (1900)*

Cooper's Law

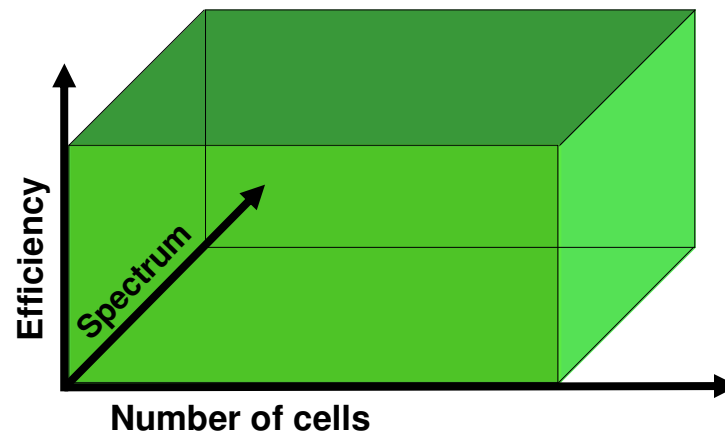


**Dr. Martin Cooper in 1982 with the DynaTAC**

# What is enabling this apparent exponential growth in wireless communications?

The capacity of a system to deliver services is defined by three main factors:

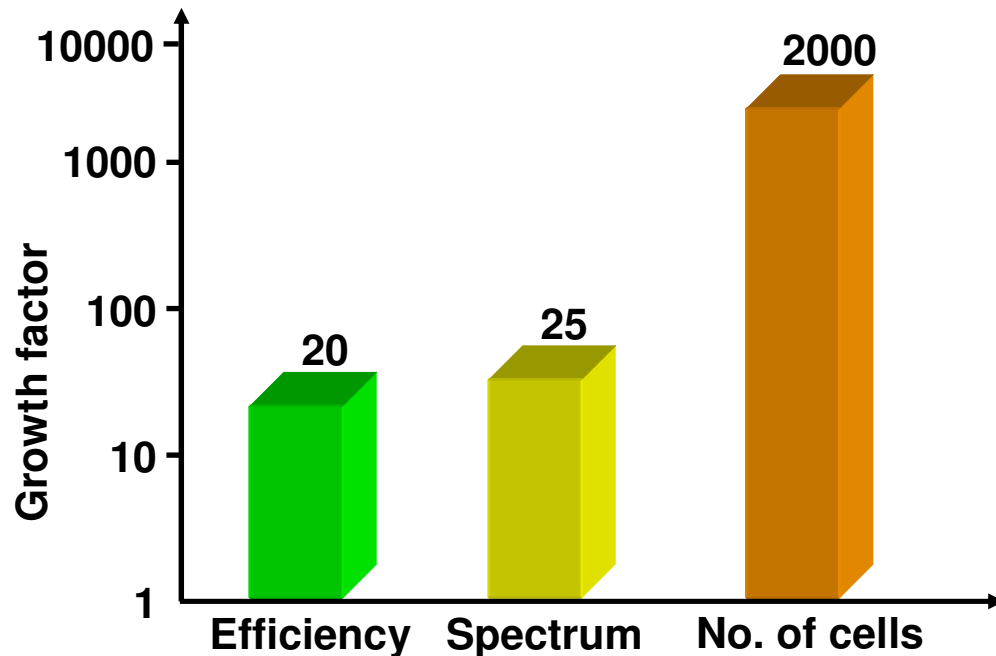
- The bandwidth of the available radio **spectrum** – in MHz
- The **efficient use** of that spectrum – bits / second / hertz
- The **number of cells** – this equates to spectrum reuse



# Growth to date dominated by increasing cell count

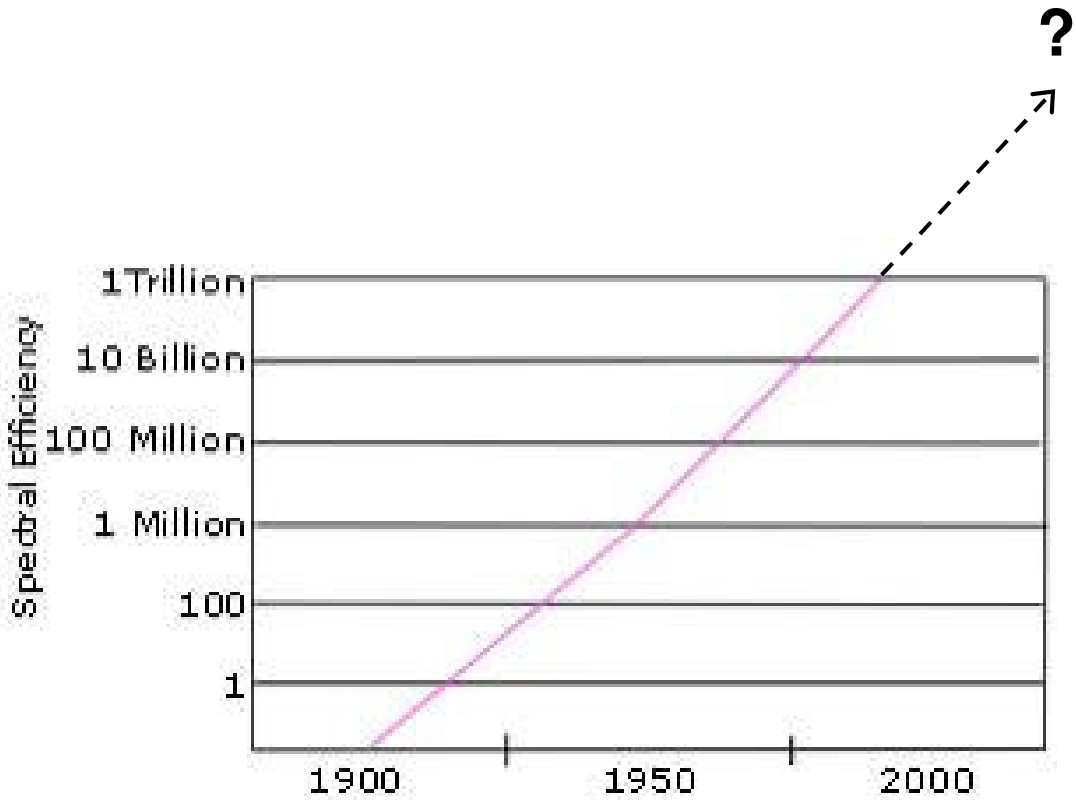
If we apply Cooper's law over the last 50 years we are looking at a growth in wireless capacity of perhaps 1,000,000

Allocating this growth between the axes of capacity looks roughly like this:



Growth has historically been dominated by the increase in the number of cells

# What is the outlook for traffic growth in the next 10 years?



The bulk of historical connections has been voice, more recently augmented by SMS

To a first approximation Cooper's law represents growth in wireless capacity

Will the historical growth continue?

What will be the demand?

And more importantly, what will be the supply?

# Predicting growth in voice and data traffic

Due to usage patterns, voice traffic might just double over the next 10 years

The potential for growth in data is not bounded by physical human attributes like:

- Number of people
- Number of mouths per person

What will fuel demand for wireless data?

- Without discussing the vexed question of the killer application, demand will largely be stimulated by the available affordable capacity
- Think hard disc drive size – there is never enough!
- So we need to assess the potential for capacity growth

# Cellular wireless peak data rates appear to be on track to grow by 100,000 between 1985 and 2015

Date	System	Peak data rate	Channel Bandwidth	Frequency reuse	Peak Spectral efficiency	Normalized efficiency
1985	AMPS	9.6 kbps	30 kHz	7 / 21	0.015	1
1992	GSM	9.6 – 14.4 kbps	200 kHz	4 / 12	0.032 - 0.048	2.1 – 3.2
1997	GPRS	171 kbps	200 kHz	4 / 12	.07	4.7
2000	EDGE	474 kbps	200 kHz	4 / 12	0.2	13.3
2003	W-CDMA	2 Mbps	5 MHz	1	0.4	26.6
2006	HSDPA	14 Mbps	5 MHz	1	2.8	187
2009	HSDPA+ 64QAM & 2x2 MIMO	42 Mbps	5 MHz	1	8.4	560
2011	LTE	100 Mbps	20 MHz	1	5	333
2012	LTE 2x2 MIMO	172.8 Mbps	20 MHz	1	8.6	576
2013	LTE 4x4 MIMO	326.4 Mbps	20 MHz	1	16.3	1087
2015	IMT-Advanced targets	1 Gbps	100 MHz	1	10	667

With such peak data rates future demand for capacity could be huge

# Is wireless keeping up with wired?

## Aug 2007: IEEE decides on next generation Ethernet standard

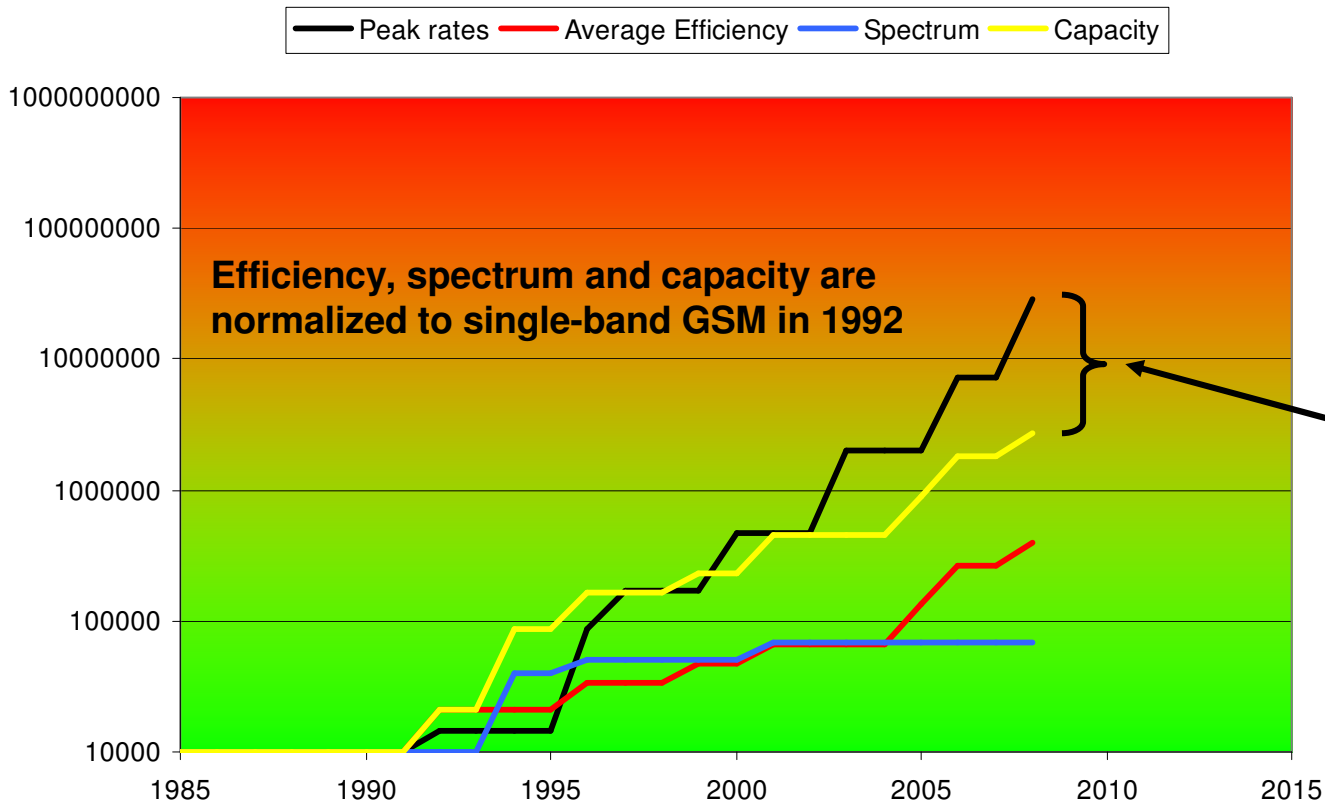
The Institute of Electrical and Electronics Engineers (IEEE) is to create a single standard that covers both **40gbps and 100gbps** Ethernet speeds. The standard should be completed in the next **two years**.



Today's Fiber capacity: 10 Gbps (OC-192)  
Theoretical capacity of a single fiber > 10 Tbps

To match **ONE** strand of fibre  
a wireless solution would need  
**2 GHz of dedicated spectrum** with  
a spectral efficiency of 5 b/s/Hz

# At today's macrocell densities, average data rates (i.e. capacity) fall behind peak data rates by 10x



The average efficiency, spectrum and capacity plots are normalized

Pk Data rates x 2800

Efficiency x 40  
Spectrum x 7

→ Capacity x 280

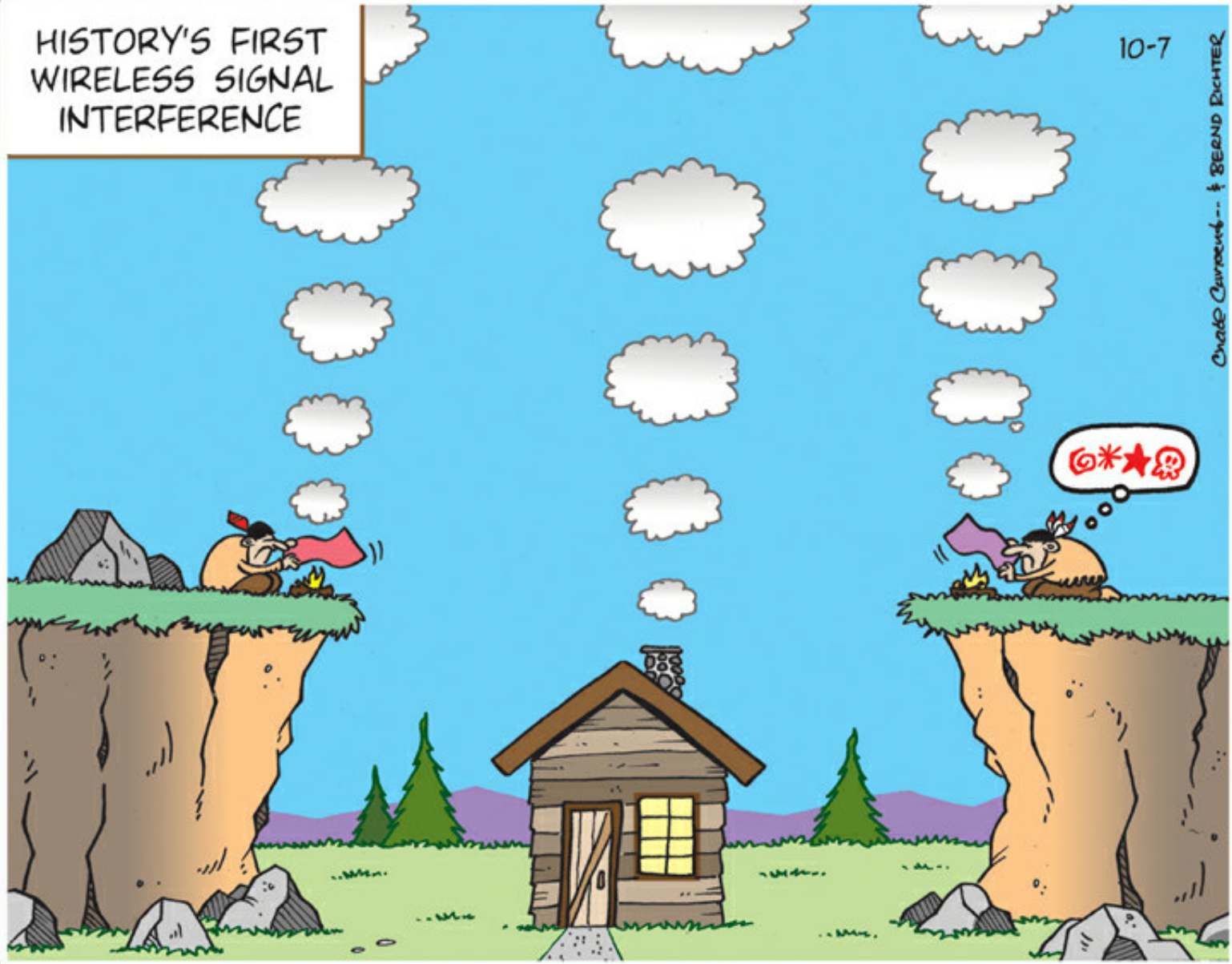
A 10x capacity gap has opened up today!

**In a loaded network the average data rate will be only 10% of the peak. Why?**

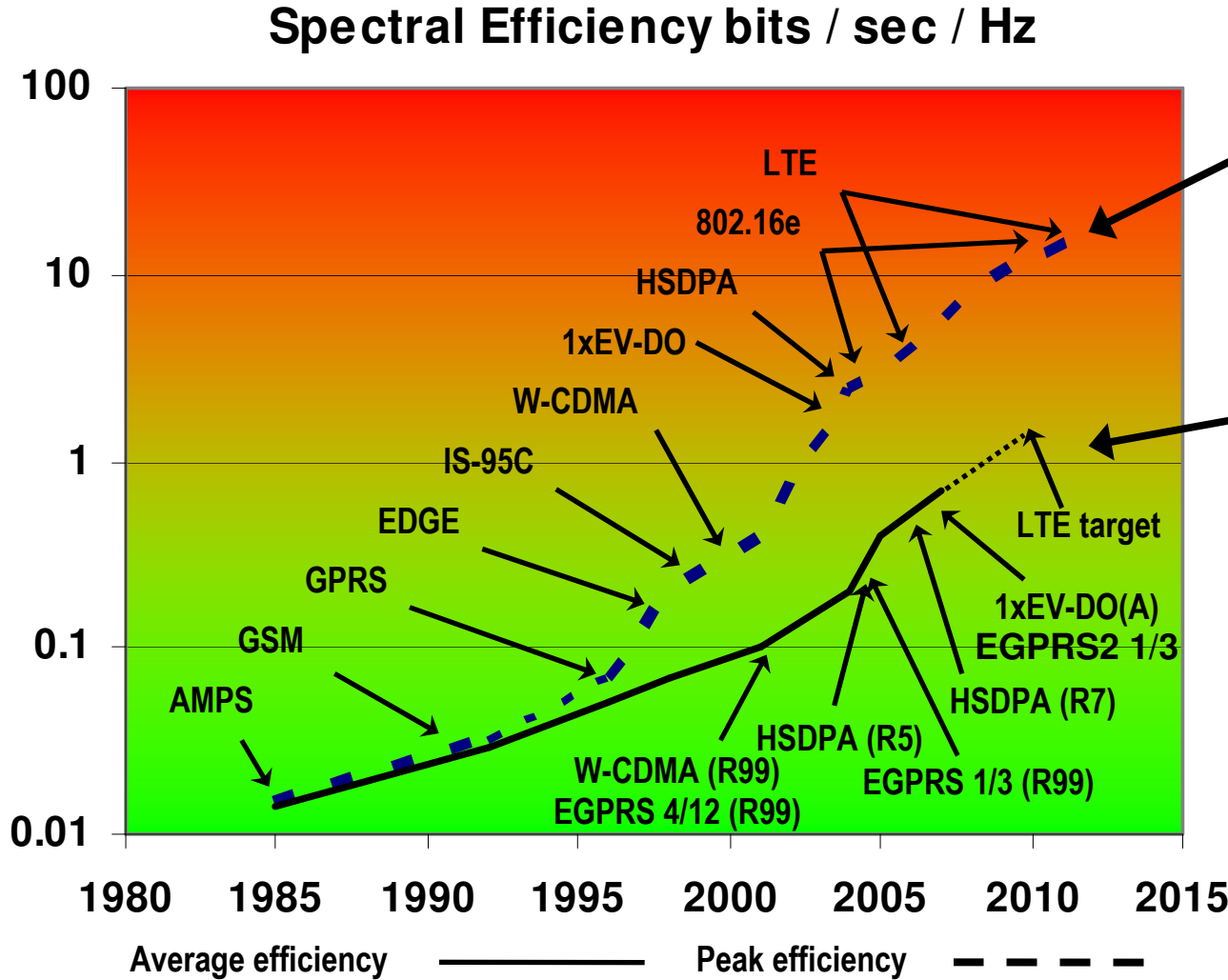
HISTORY'S FIRST  
WIRELESS SIGNAL  
INTERFERENCE

10-7

CHUCK CHARNOVICH -- & SEBASTIAN RICHTER



# Growth in peak / average spectral efficiency by technology



Peak efficiency lies around this line

Average efficiency and hence capacity growth of deployed systems lags well behind and will level off due to inter-cell interference

Peak efficiency drives up air interface **cost & complexity**

**You pay for the peak but experience the average**

# Assessing the outlook for capacity growth over the next 10 years

- **Spectrum**
- Efficiency
- Number of Cells

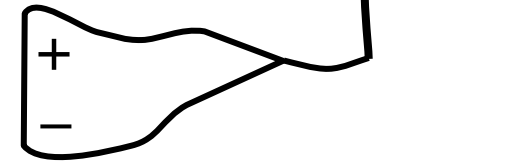
# One digital band in 1990 to twenty five in 2008

Band	Uplink		Downlink		Duplex	Mode
1	1920	1980	2110	2170	130	FDD
2	1850	1910	1930	1990	20	FDD
3	1710	1785	1805	1880	20	FDD
4	1710	1755	2110	2155	355	FDD
5	824	849	869	894	20	FDD
6	830	840	875	885	35	FDD
7	2500	2570	2620	2690	50	FDD
8	880	915	925	960	10	FDD
9	1749.9	1784.9	1844.9	1879.9	60	FDD
10	1710	1770	2110	2170	340	FDD
11	1427.9	1452.9	1475.9	1500.9	23	FDD
12	698	716	728	746	12	FDD
13	777	787	746	756	21	FDD
14	788	798	758	768	20	FDD
15	1900	1920	2600	2620	700	FDD
16	2010	2025	2585	2600	575	FDD
17	704	716	734	746	30	FDD
33	1900	1920	1900	1920	0	TDD
34	2010	2025	2010	2025	0	TDD
35	1850	1910	1850	1910	0	TDD
36	1930	1990	1930	1990	0	TDD
37	1910	1930	1910	1930	0	TDD
38	2570	2620	2570	2620	0	TDD
39	1880	1920	1880	1920	0	TDD
40	2300	2400	2300	2400	0	TDD

Lots of bands but overlapping and not all in the same geography

# IMT Spectrum

Software defined amplifier & antenna

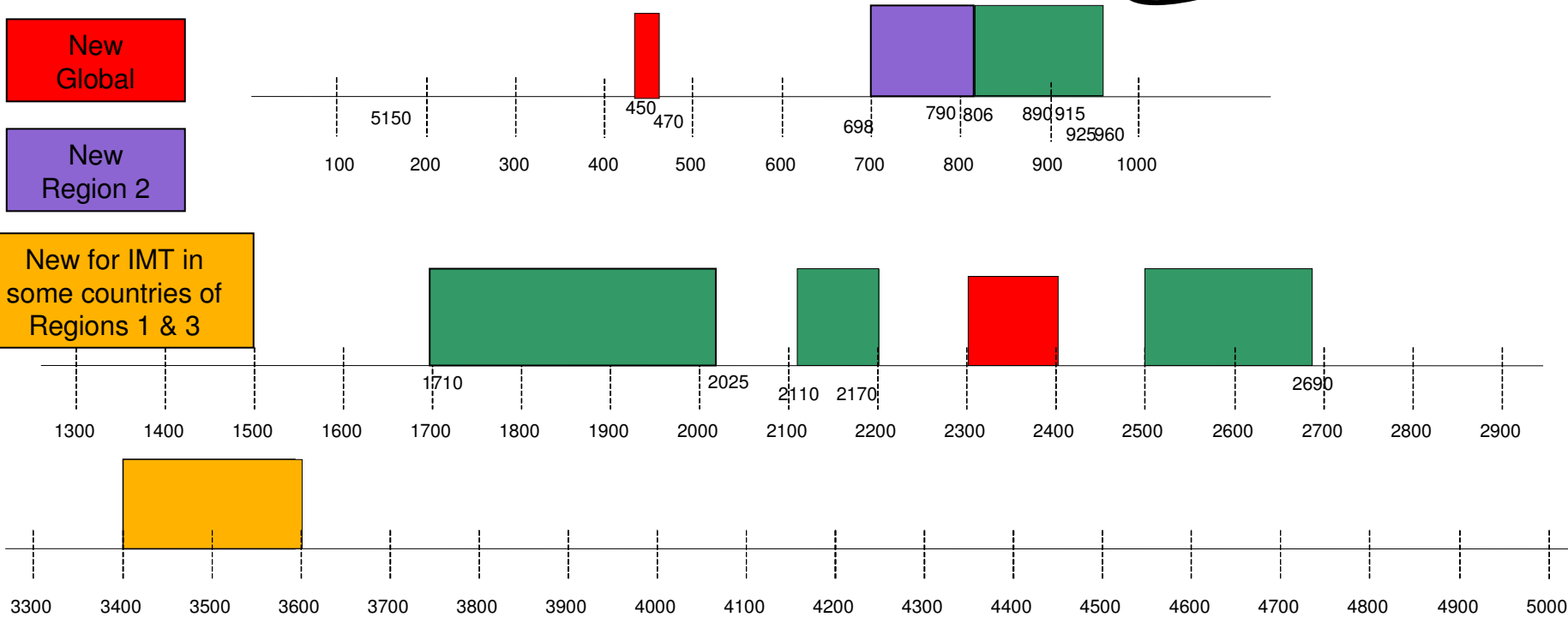


Existing IMT identified

New Global

New Region 2

New for IMT in some countries of Regions 1 & 3



New spectrum is limited. Aggregation of multiple bands adds cost and complexity to the terminals. SDR is not yet the answer.

# Spectrum upside for any one geography

Assume the European model of 340 MHz:

- 35+35 MHz of GSM @ 900 MHz
- 75 + 75 MHz of GSM @ 1800 MHz
- 60 + 60 MHz of UMTS FDD @ 2.1 GHz

Add 70 MHz from UHF band

Add max 200 MHz from 2.6 GHz band

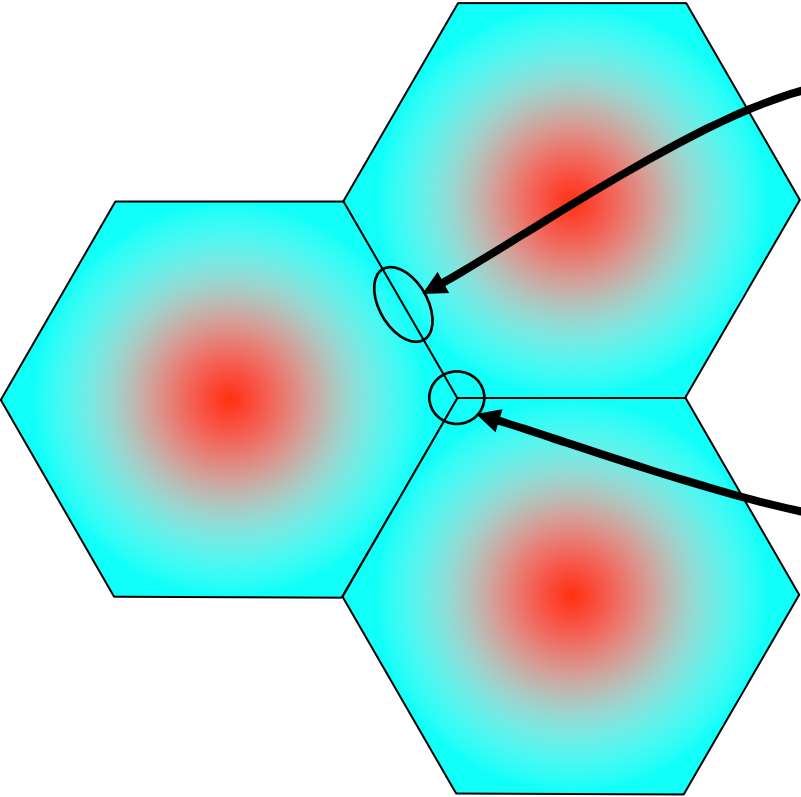
Plus some 3.5GHz?

Spectrum upside could be 2x

# Assessing the outlook for capacity growth over the next 10 years

- Spectrum
- **Efficiency**
- Number of Cells

# Efficiency is limited by inter-cell interference – the geometry factor



Low SNR

High SNR

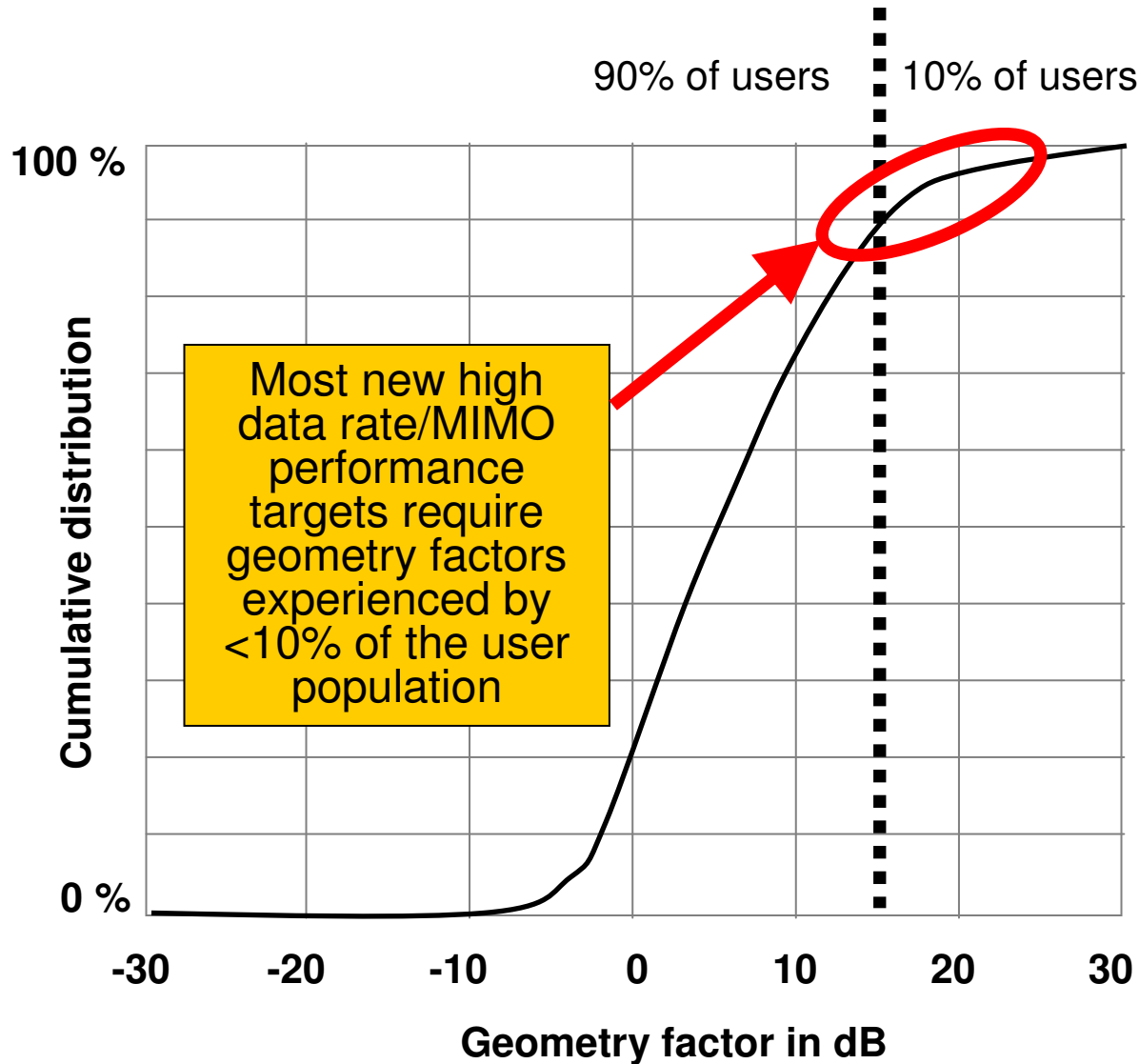
The geometry factor is the ratio between the serving cell power and interfering cells + noise

At the boundary of any two cells the geometry factor will not exceed -3dB

At the boundary of any three cells the geometry factor will not exceed -4.8 dB

No one has yet invented a spatially aware electromagnetic wave that stops at the desired cell boundary!

# Geometry factor distribution in urban cells



This plot shows the variation in geometry factor across a typical outdoor urban cell

Very high spectral efficiency is only seen when the geometry factor is above 15 dB, which is an environment that 90% of the user population will not experience

In-building penetration loss will degrade performance further

This puts a finite and very low limit on indoor performance when using outdoor transmission systems

# HSDPA cell throughput and geometry factor vs. coverage

>20 dB  
5%

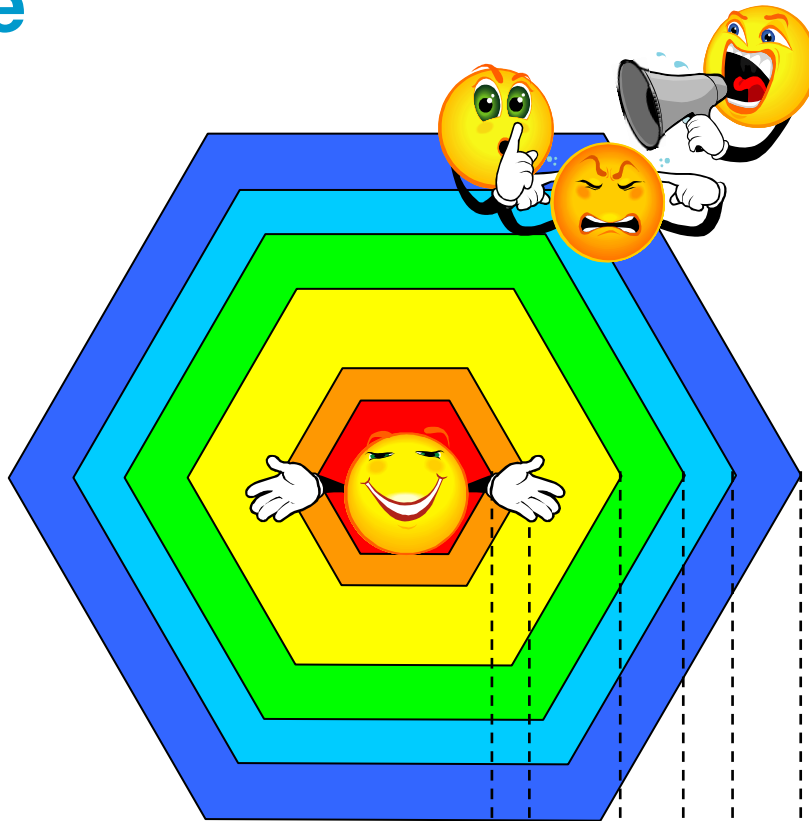
>15 dB  
10%

>10 dB  
30%

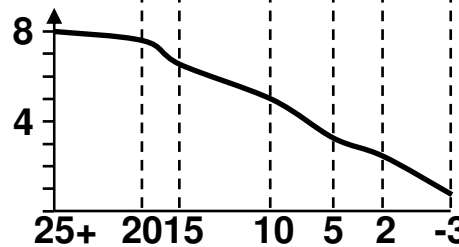
>5 dB  
50%

>2 dB  
70%

>-3 dB  
100%



Mbps cell throughput vs. G factor



Rel-7 Type 3 receiver  
(Equalizer plus receive diversity)

Figures derived from typical urban G factor distribution and 3GPP TS 25.101 v7.9.0 Tables 9.8D3, 9.8D4 & 9.8F3 for 3 km/h

Any point on the graph represents the entire cell capacity if all users experience that G factor

The average cell throughput is around 3 Mbps or 0.6 b/s/Hz

# Average efficiency upside

Remaining gains in efficiency will come from:

- Wider channels enabling freq dependent scheduling
- MIMO & Beamforming
- Interference cancellation
- Advanced coding techniques

All high efficiency techniques increase system complexity and costs

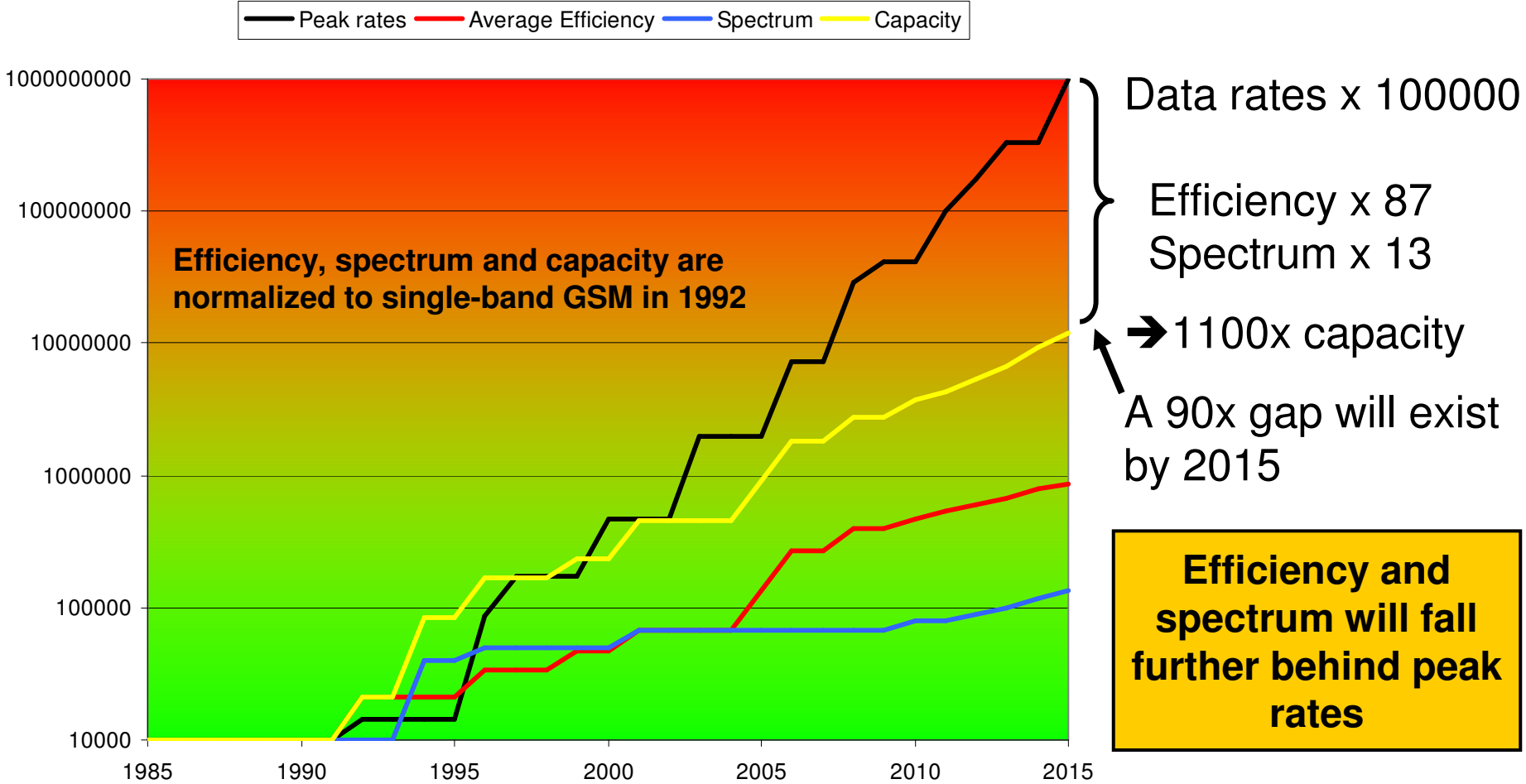
Driving up today's best performance - which lies somewhere in the range 0.4 b/s/Hz to 0.8 b/s/Hz will be hard work

- Average efficiency is not significantly impacted by increasing the peak efficiency due to its low-coverage

Historical average efficiency has been improving around 3x per decade

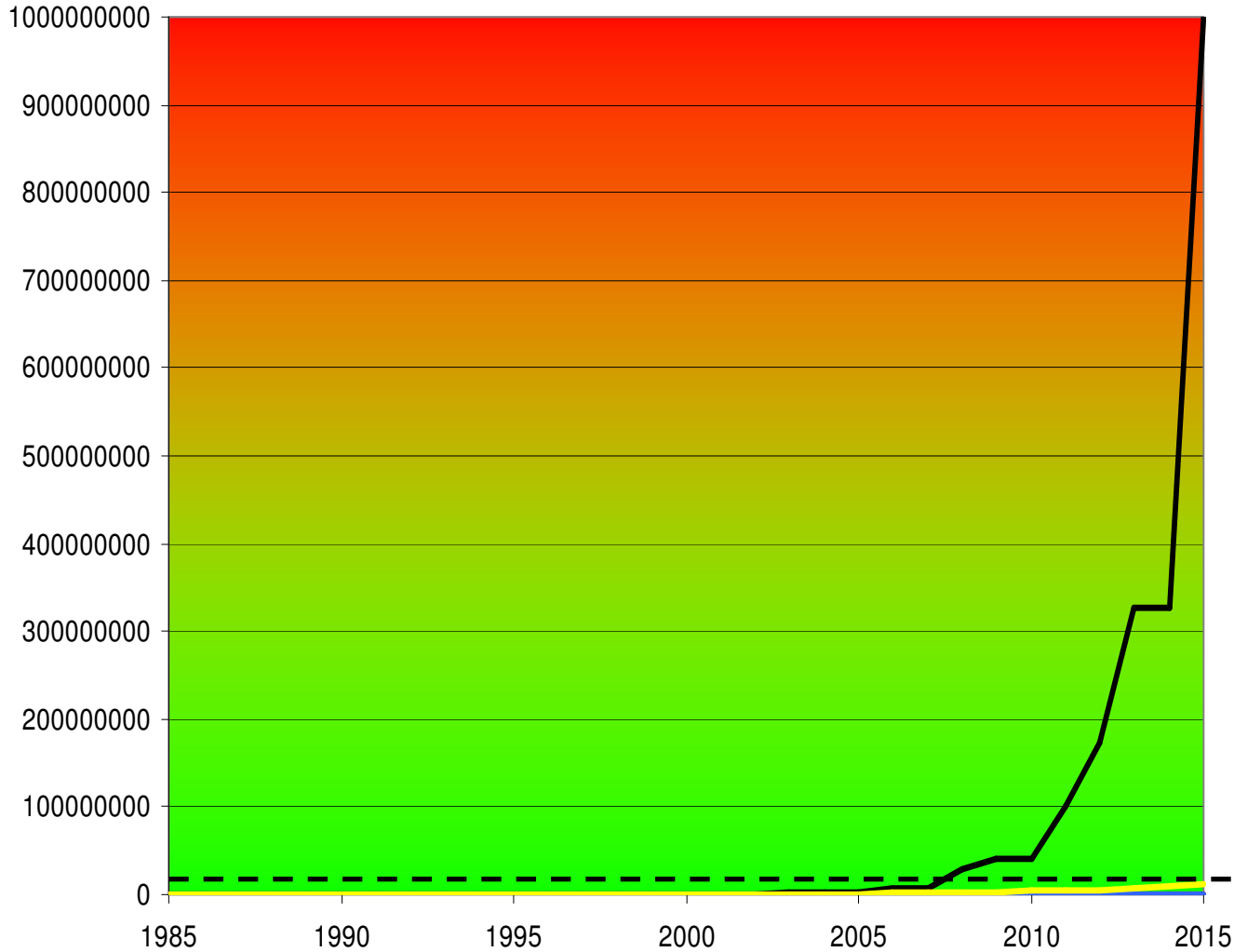
A rough figure for affordable average efficiency gains is probably going to be similar to the historical trend at around 3x

# Projecting ahead shows the gap between average and peak rates in loaded cells will grow to 90x



# And on a linear scale

— Peak rates — Average Efficiency — Spectrum — Capacity



**Macrocell reality lies somewhere below this line**



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**Top end wireless is a bit like the top end automotive**

- **It is undeniably real**
- **But is it affordable?**



**And once you have purchased it, where and how often can you really experience it?**

**1001 bhp**

*Top Speed: 253 mph*

**Top Speed – 253 mph**

**0 – 60 mph in 2.5 seconds**

**0 – 125 mph in 7.5 sec**

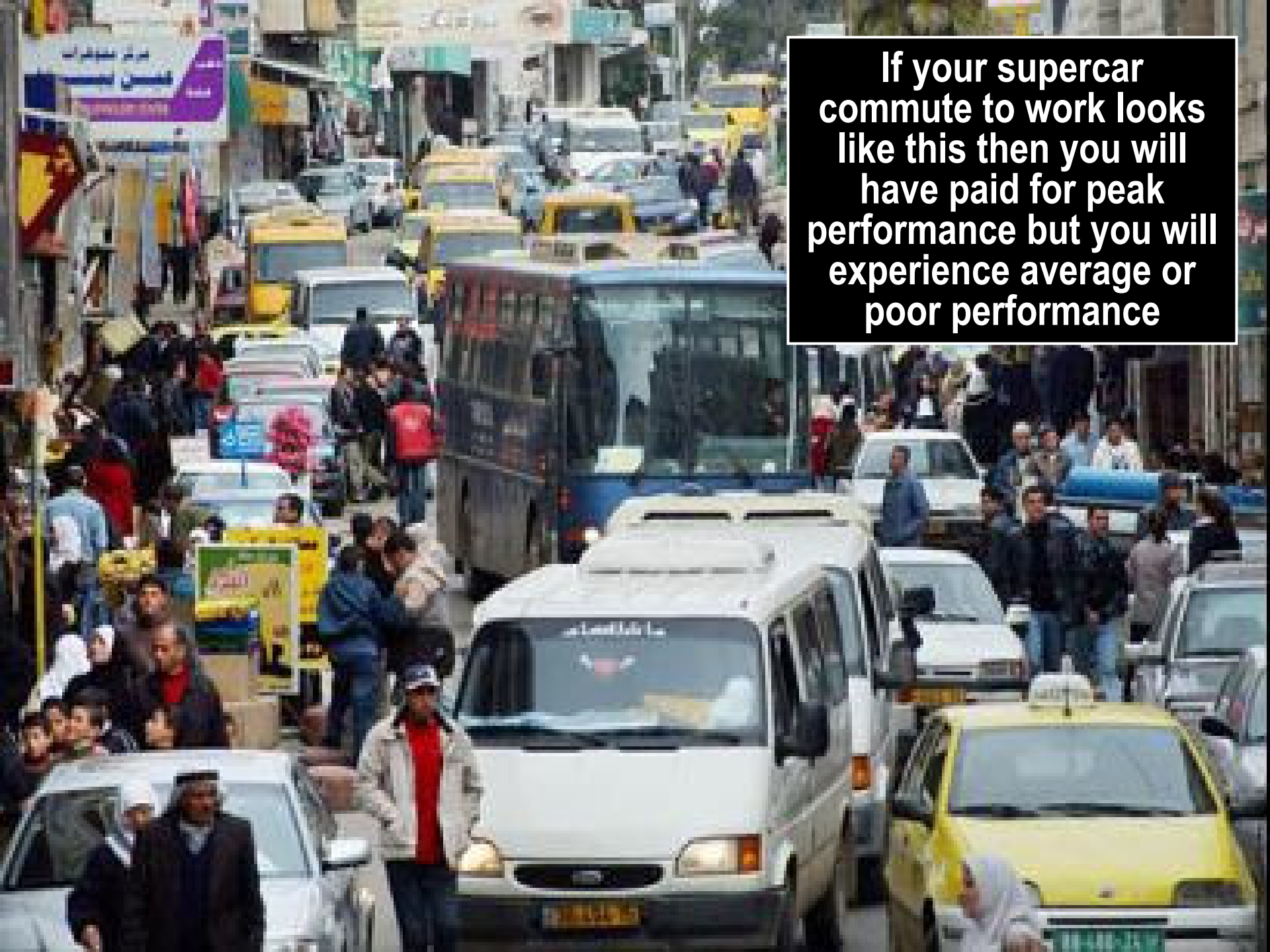
**0 – 250 mph in 16.7 sec**

**250 – 0 mph in 9.8 sec**

**At top speed, empties its fuel tank in 12 minutes!**



**Price: \$ 1,500,000 (plus tax!)**



**If your supercar commute to work looks like this then you will have paid for peak performance but you will experience average or poor performance**

# Assessing the outlook for capacity growth over the next 10 years

- Spectrum
- Efficiency
- **Number of Cells**

# Cell number upside

History shows that the bulk of growth in wireless capacity has come from increasing the number of cells

Today we are around one cell per 1000 users

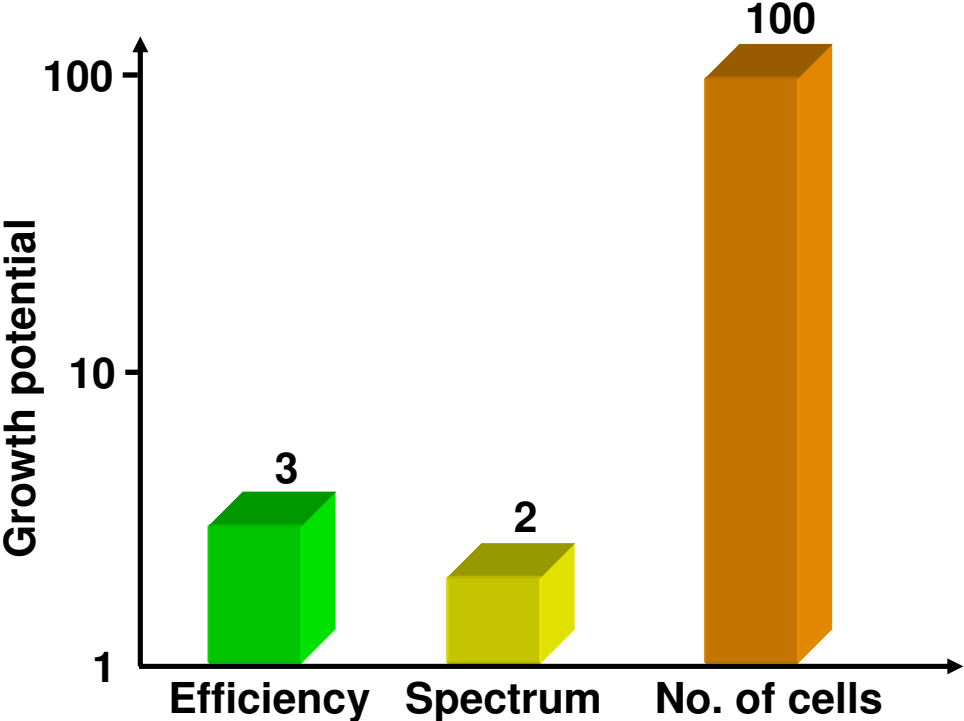
This has huge potential to change

It is not unreasonable to assume one cell per ten users which could be achieved with deployment of home base stations or femtocells into 30% of households

From the operator's perspective, growing capacity by having the end user pay for the CapEx and OpEx is very attractive!

With this assumption the upside for cell numbers could easily be in the region of 100x

# Comparing wireless growth potential for the next decade



The historical domination of growth delivered by increasing cell numbers will continue into the next decade

The alternatives of improving average efficiency and adding spectrum look like continuing at their historical levels which is around 15x less significant

# Example of femtocell impact on throughput\*

HSDPA macrocell, single Rx + equalizer

15 code 64QAM, 20 Mbps peak

34 randomly distributed users

What is the combined throughput and why?

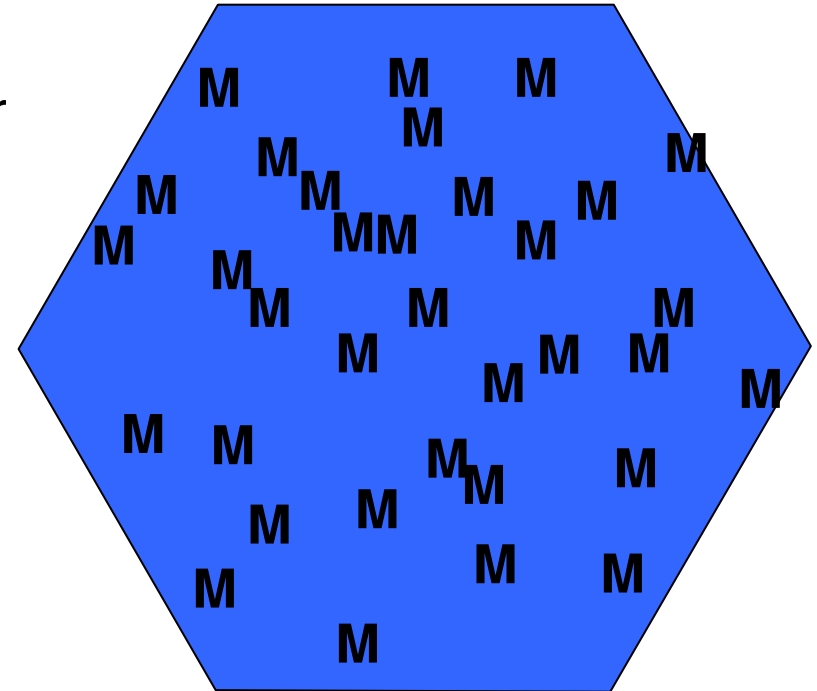
680 Mbps

20 Mbps

13 Mbps

1.3 Mbps

(0.26 b/s/Hz)



That is an average throughput of 40 kbps

\* Source: 3GPP RAN WG4 R4-081344

# Example of femtocell impact on throughput

Using the same macrocell add 96 femtocells

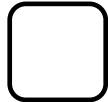
24 users migrate to femtocells

10 users remain on the macrocell

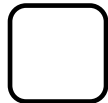
What is the combined throughput and why?



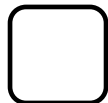
**270 Mbps**



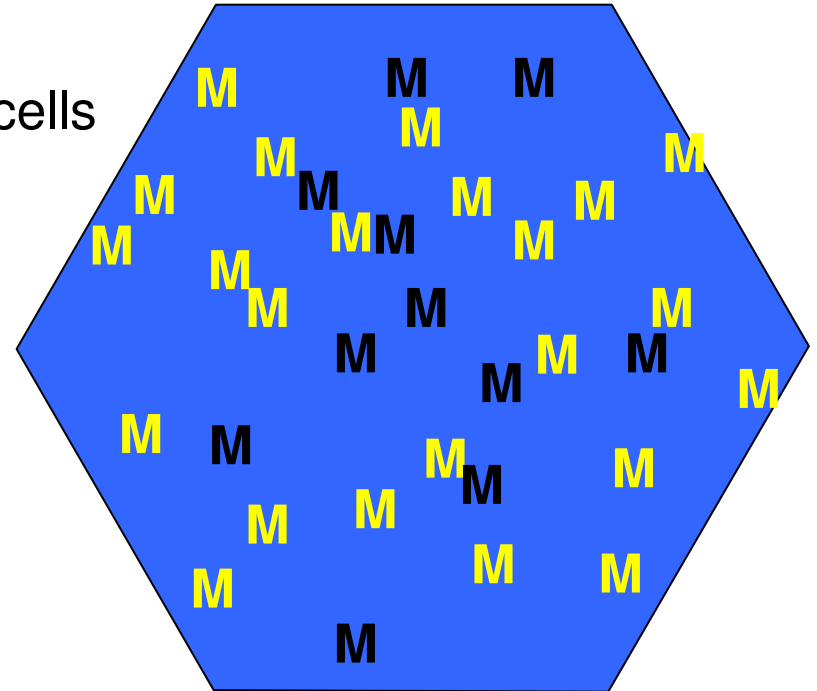
**27 Mbps**



**2.7 Mbps**



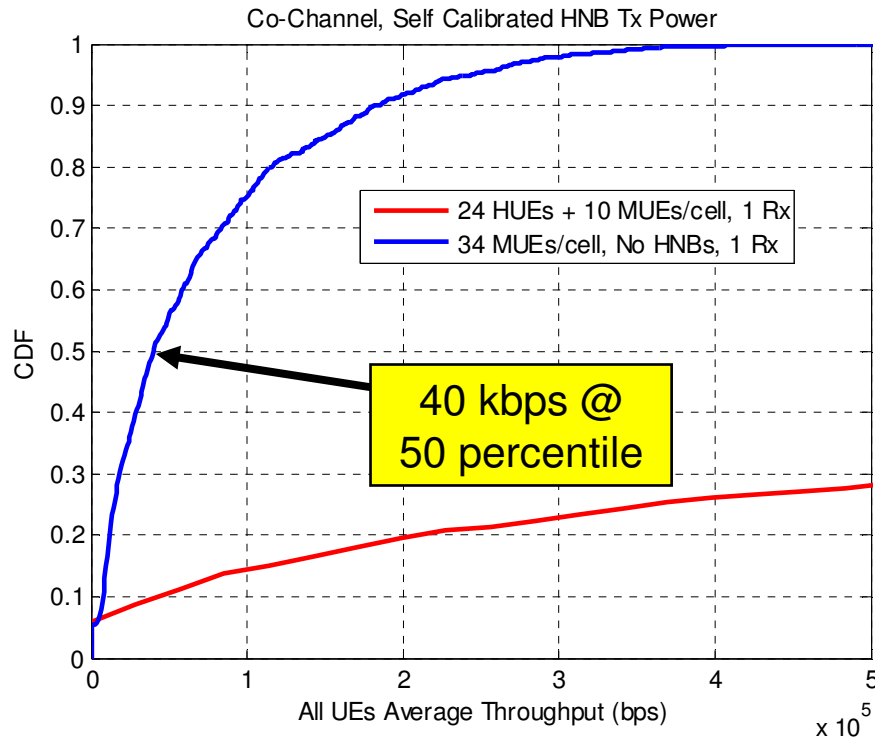
**1.3 Mbps**



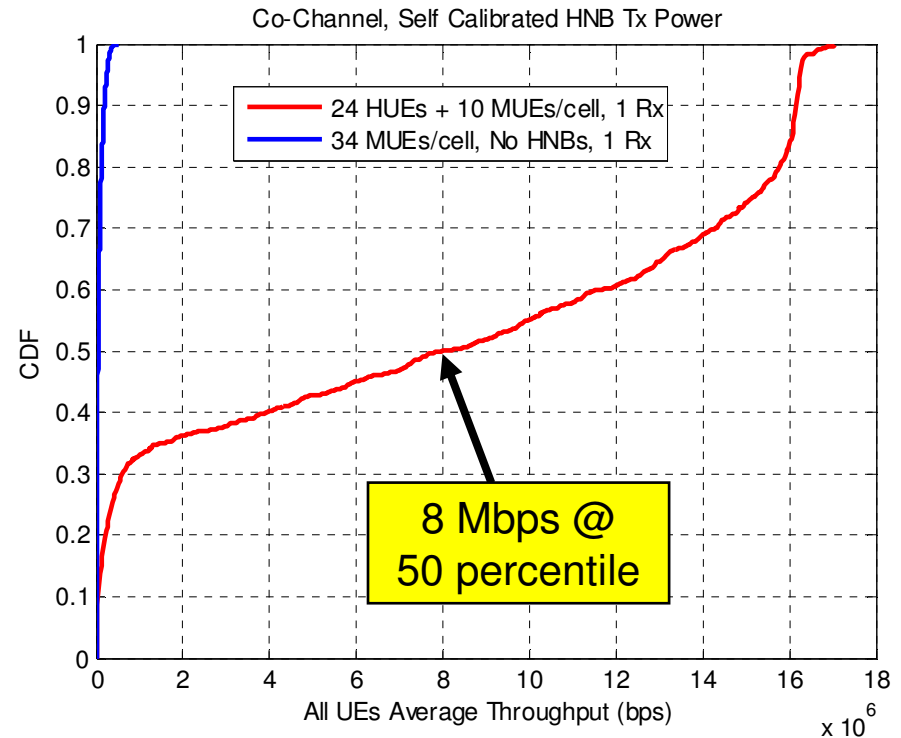
**That is an average  
throughput of 8 Mbps  
A 200x improvement!**

**The remaining macrocell users  
go from 50 kbps to 170 kbps**

# CDF of throughput with and without femtocells



Detail showing 40 kbps median for macrocell



Full CDF showing 8 Mbps median for macrocell plus 24 active femtocells

**Projected spectrum and efficiency gains could push the blue trace to the right by 6x, this femtocell study moved it by 200x**

# The macrocellular dilemma

The key attributes for mobile broadband are:

1. High capacity & data rates
2. Ubiquitous coverage
3. Low cost

Without small cells,  
pick any two!

# Which small cell technology will prevail? What about plain old WiFi?

Love it or hate it, WiFi is here to stay

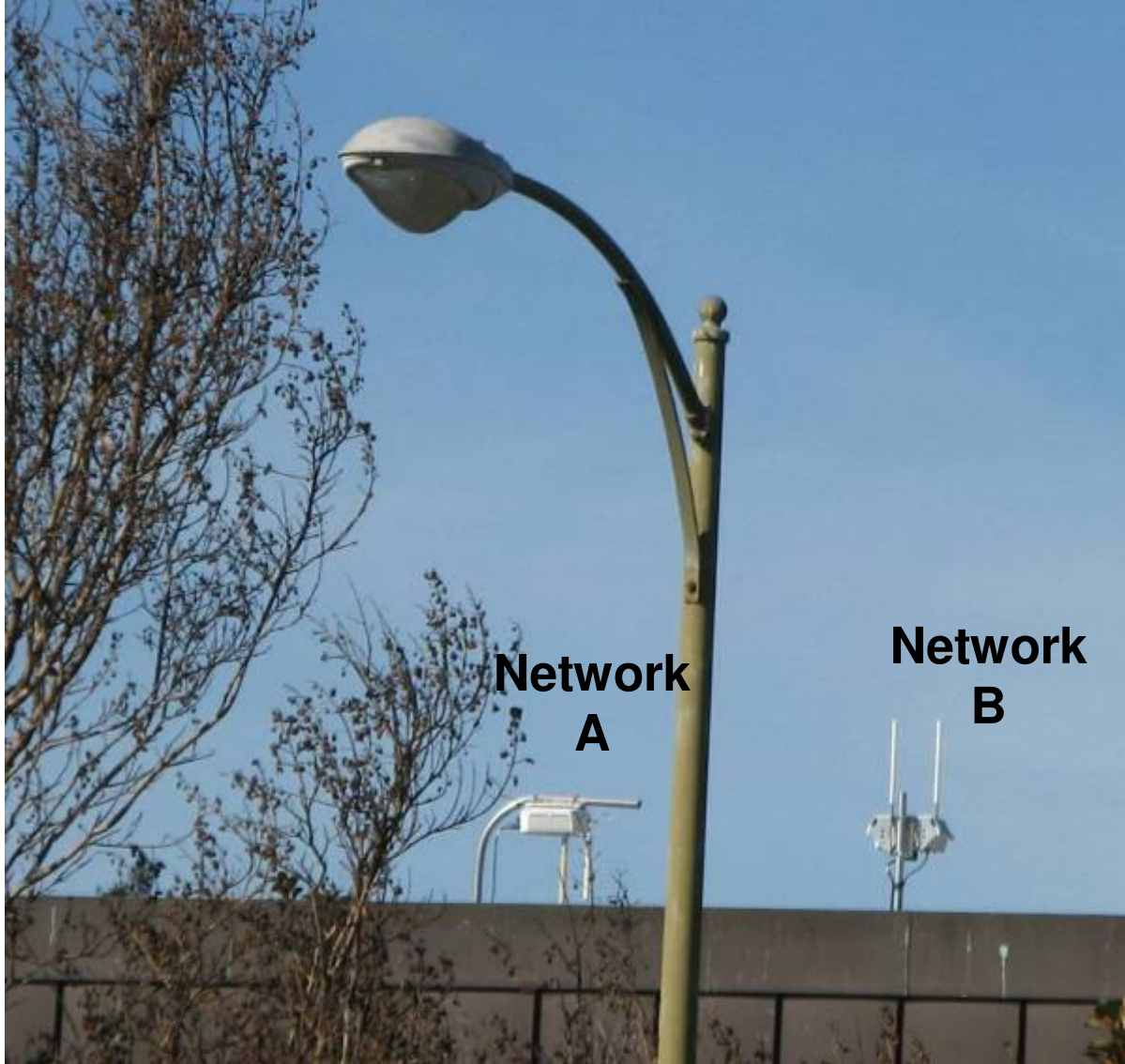
WiFi today is by far the biggest provider of home and nomadic wireless data services and so can't be ignored.

By cellular standards it is a crude technology

- No power control
- No frequency awareness
- Limited mobility and handover capability
- Limited range

But WiFi's simplicity and low cost has led to mass deployment

# The Wild West of municipal WiFi



AP Antenna 7dBi

Site to site pathloss ~60 dB

WiFi ACLR1 ~30 dB

AP TX power 23 dBm

Uplink pathloss ~90 dB

Client power ~15 dBm

Client antenna -5 dBi

RX signal ~ -73 dBm

RX interference ~ -53 dBm

**20 dB of interference!  
Wireless anarchy even  
on adjacent channels!**

# Who needs adjacent channels anyway?

Network Stumbler - [20071114230750.ns1]

Channel	MAC	SSID	Speed	Enc...	Signal+	Noise-	SNR+
1	000D970405FA	eConnectSR	54 Mbps		-85	-100	15
	0040962A4C82	eConnectSR	11 Mbps	WEP	-81	-100	19
	000D970405FA	eConnectSR	54 Mbps		-65	-100	35
	001AA2825D30	eConnectSR	54 Mbps	WEP	160	-100	160
	0040962A4C82	hpsetup	11 Mbps		-81	-100	19
	8ECB1FE30CCE	VeVa	54 Mbps	WEP	-75	-100	25
3	001CB3ADD660	VeVa	54 Mbps	WEP	-75	-100	25
	001BD58FE030	lilchicken	54 Mbps		160	-100	160
	0014BF7DB936	tsunami	11 Mbps	WEP	160	-100	160
5	001BD58FE030	Pranashakti	54 Mbps	WEP	160	-100	160
	00095B99BC50	Lindaz_network	54 Mbps	WEP	160	-100	160
6	00095B99BC50	Lindaz_network	54 Mbps	WEP	160	-100	160
	000D721EBF69	BlAWiFi	54 Mbps	WEP	-91	-100	9
	00131023D88C	linksys_SES_59876	54 Mbps	WEP	160	-100	160
	00149532A412	2wIRE 430	54 Mbps	WEP	160	-100	160
	00149584D7D9	2wIRE552	54 Mbps	WEP	-81	-100	19
	00149584D7D9	2wIRE552	54 Mbps	WEP	-81	-100	19
	0014BF7DB936	000D721EBF69	54 Mbps	WEP	-61	-100	33
	0014BF7DB936	0014BF7DB936	22 Mbps	WEP	-61	-100	33
	0014BF7DB936	0014BF7DB936	22 Mbps	WEP	-61	-100	33
	0014BF7DB936	0014BF7DB936	22 Mbps	WEP	-61	-100	33
	0014BF7DB936	0014BF7DB936	22 Mbps	WEP	-61	-100	33
7	0018F861B0C8	Norcal	54 Mbps	WEP	160	-100	160
	0040962A4C82	Norcal	54 Mbps	WEP	160	-100	160
	000D721EBF69	zoom1144	54 Mbps	WEP	160	-100	160
	000D721EBF69	zoom1144	54 Mbps	WEP	160	-100	160
	000C9401B51	hpsetup	11 Mbps		160	-100	160
	000C9401B51	hpsetup	11 Mbps		160	-100	160
	00088576742D	City of SR PUBLIC	54 Mbps	WEP	160	-100	160
	00088576742D	City of SR PUBLIC	54 Mbps	WEP	160	-100	160
	0040F8414B17	BNDEMO	11 Mbps	WEP	160	-100	160
	0040F8414B17	BNDEMO	11 Mbps	WEP	160	-100	160
9	001217271A36	Impact	54 Mbps	WEP	159	-100	159
	001217271A36	Impact	54 Mbps	WEP	159	-100	159
	00409629EC09	Impact	11 Mbps	WEP	160	-100	160
	00409629EC09	Impact	11 Mbps	WEP	160	-100	160
	001AE3D03FE1	eConnectSR INTERNAL	54 Mbps	WEP	160	-100	160
	001AE3D03FE1	eConnectSR INTERNAL	54 Mbps	WEP	160	-100	160
	0018F85C2B64	SRSquare	54 Mbps	WEP	-94	-100	6
	0018F85C2B64	SRSquare	54 Mbps	WEP	-94	-100	6
	001AE3D03FE3	srcam	54 Mbps	WEP	160	-100	160
	001AE3D03FE3	srcam	54 Mbps	WEP	160	-100	160
	0019E4525159	2wIRE913	54 Mbps	WEP	160	-100	160
10	0019E4525159	2wIRE913	54 Mbps	WEP	160	-100	160
	00173F91C3B9	WaveLAN Network	54 Mbps	WEP	160	-100	160
	00173F91C3B9	WaveLAN Network	54 Mbps	WEP	160	-100	160
	0018F85C2B64	Impact_Ste_106	48 Mbps	WEP	-82	-100	18
	0018F85C2B64	Impact_Ste_106	48 Mbps	WEP	-82	-100	18
	0019E4525159	City of SR GUEST	54 Mbps	WEP	160	-100	160
	0019E4525159	City of SR GUEST	54 Mbps	WEP	160	-100	160
11	001AE3D03FE0	NoCatB-SCT	54 Mbps		-90	-100	10
	001AE3D03FE0	NoCatB-SCT	54 Mbps		-90	-100	10

Ready | 6 APs active | GPS: Disabled

Only WiFi channels 1, 6 and 11 avoid overlap

Eleven APs broadcasting on channel 11!

How can this ever work!!!

Being a collision-based protocol it sort of works even here

# Often the “best” technology doesn’t win

- Ethernet vs. Token ring
- 802.11b vs. HiperLAN
- Windows 3.1 vs. Unix
- Iridium vs. GSM

**“Perfection is the enemy  
of the good”**

Gustav Flaubert  
French Novelist 1821 - 1880

And now...

- McDonalds vs. McCaw?

## **McDonald’s offers free Wi-Fi in U.K.**

**Reuters:** McDonald's has said it will offer free wireless Internet access at its 1,200 U.K. restaurants. The move makes the fast-food chain the country's biggest provider of free wireless broadband access.

Anyone fancy a nybble before dinner?

I'm going to McDonald's →

Would you like bytes with that?



# Can femtocells outperform and replace WiFi?

The potential for cellular femtocells to deliver the future growth of wireless is very real but:

- The industry remains largely focussed on improving efficiency which is driving up cost and complexity
- Many of the engineering challenges of femtocells remain to be solved

# Femtocell key challenges

- It's all about interference mitigation!
- Co-channel deployment looks very problematic except for rural
- Adjacent channel seems possible
- Regulatory aspects – need GPS for authentication
- A hackers paradise – build your own cellular network...
- Open vs. closed access
- Business models
  - Tied to operator
- Net neutrality – who owns the backhaul?
  - Could blow femtocell competition off the planet – will vary by country
- Could it hurt my cat?
  - Possible public backlash over radiation concerns?

# In a mature market, Value > price > cost

Service \ Price	Data rate / volume	Price €	Cost / MByte	Price / MByte	Relative price
SMS	160 Bytes	€0.15 / message	€ X	€1000	400,000
Voice	10 kbps	€0.05 to €0.5 / minute	€ Y	€ 0.7 - € 7	300 - 3000
Data service (capped at 3 Gbytes)	3 GBytes	€20 / month	€ Y/5	€ 0.007	3
Unicast Mobile TV (Capped at 50 hrs)	50 Hours @ 100 kbps	€5 / month	€ Y/5	€ 0.0023	1

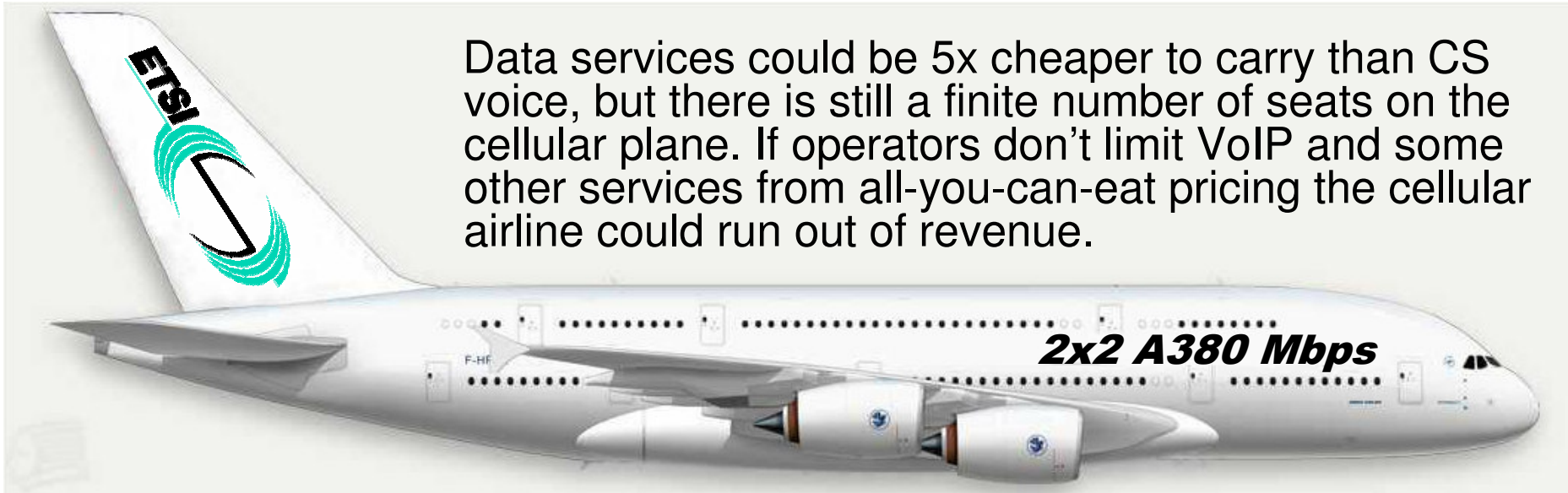
As data rates rise the user value per MByte plummets but the cost of delivery remains high. Flat rate pricing encourages unsustainable use of highly valuable macro wireless resources

# Data services – the killer app?

Circuit-switched voice services and SMS are the profit backbone of the cellular industry. Like first and business class passengers paying € 0.7 to € 1000 per seat (MByte).

Now voice, video and message services over an “all-you-can-eat” or capped data service, paying perhaps € 0.007 per seat in the hold!

Data services could be 5x cheaper to carry than CS voice, but there is still a finite number of seats on the cellular plane. If operators don't limit VoIP and some other services from all-you-can-eat pricing the cellular airline could run out of revenue.



Users associate VoIP with low or no cost – this does not work for cellular  
Cellular can't afford internet radio or TV over low-price data service plans

# Comparison of traditional cellular vs. hotspot for data delivery over next decade

	Macro/Micro	Hotspot (femtocell)
Capacity	6X	100x ?
Coverage	Reducing (for higher rates)	Where its needed
Complexity	Growing	Low, stable
Cost per bit	High and not falling fast enough	Very low

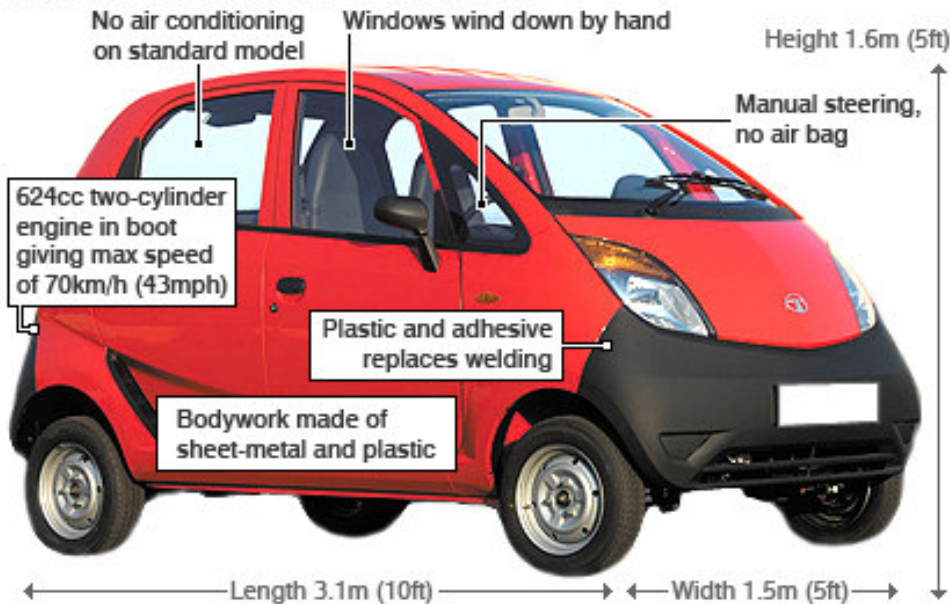
Improvements to the macro network e.g. EDGE Evolution, HSPA+ and LTE need to continue but the bulk of the traffic growth and high data rates will be delivered by small cell technology

# Battle for the car mass market: Tata Nano vs. Bugatti Veyron

**\$2,500**

**\$1,500,000**

## WHAT MAKES THE TATA NANO SO CHEAP?



**Wi-Fi?**

**4G?**

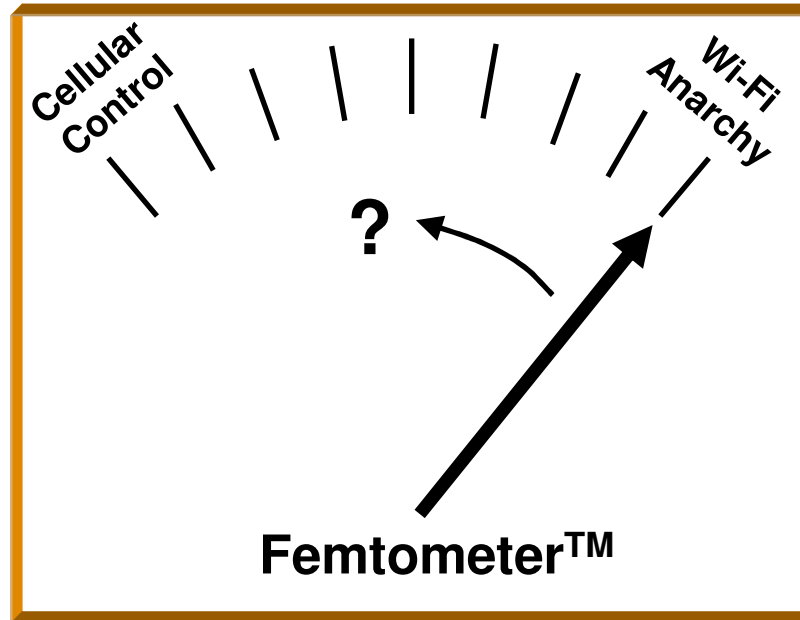
**And the winner is...**

# Which hotspot technology will win?

The answer lies between the extremes of highly regulated femtocellular or the anarchy of Wild West WiFi:



↑  
**Cellular control**



Today the needle is moving to the left. How far will it swing?



↑  
**WiFi enabled iPhone**

**Thank you for listening!**

