Trends in Wireless Communications

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The Cell Phone Has Become the Biggest Platform Created

~4.6B Total Wireless Subscribers

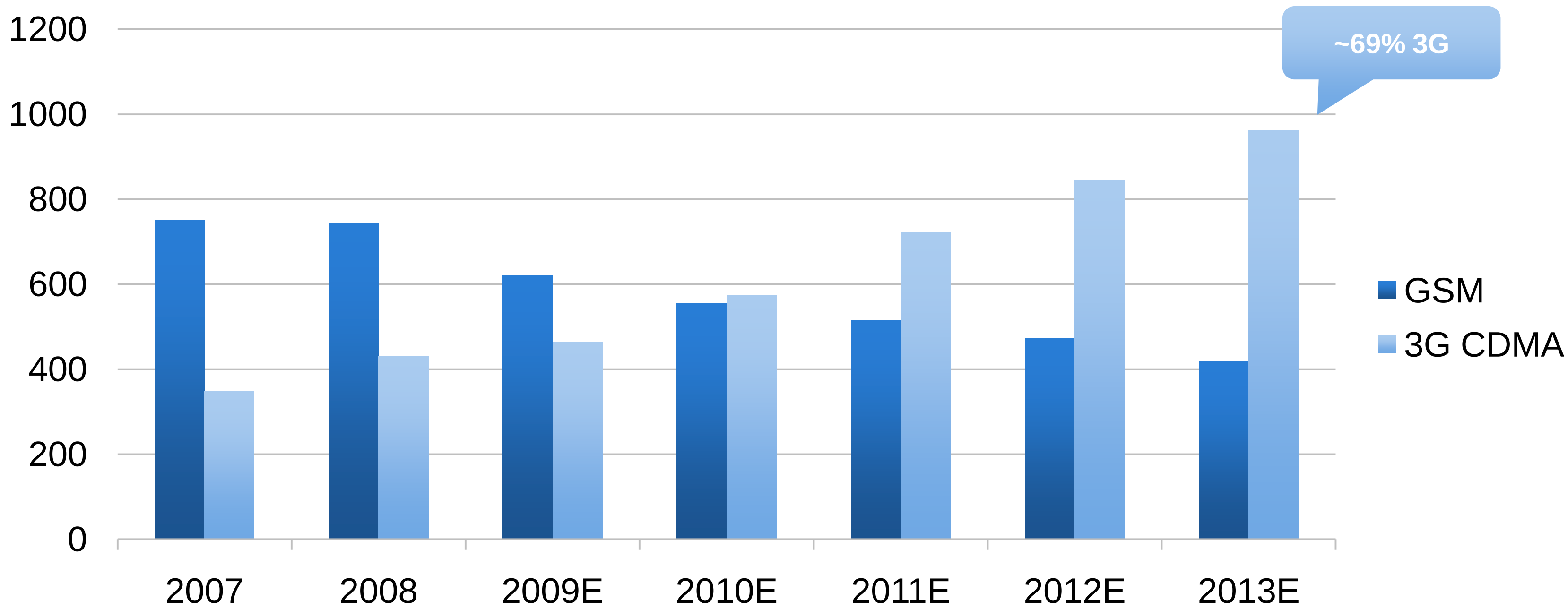
~945M 3G Subscribers Today

Expected to be **~2.7B** by **2014**

Source: 3G subs,Wireless Intelligence estimates as of Nov. 2, 2009 for the quarter ending Sep. 30, 2009.
Commercial 3G operators,CDG and GSA as of Oct. 2009

Migration from 2G to 3G Continues to Accelerate

HANDSET SHIPMENTS* (MILLIONS)

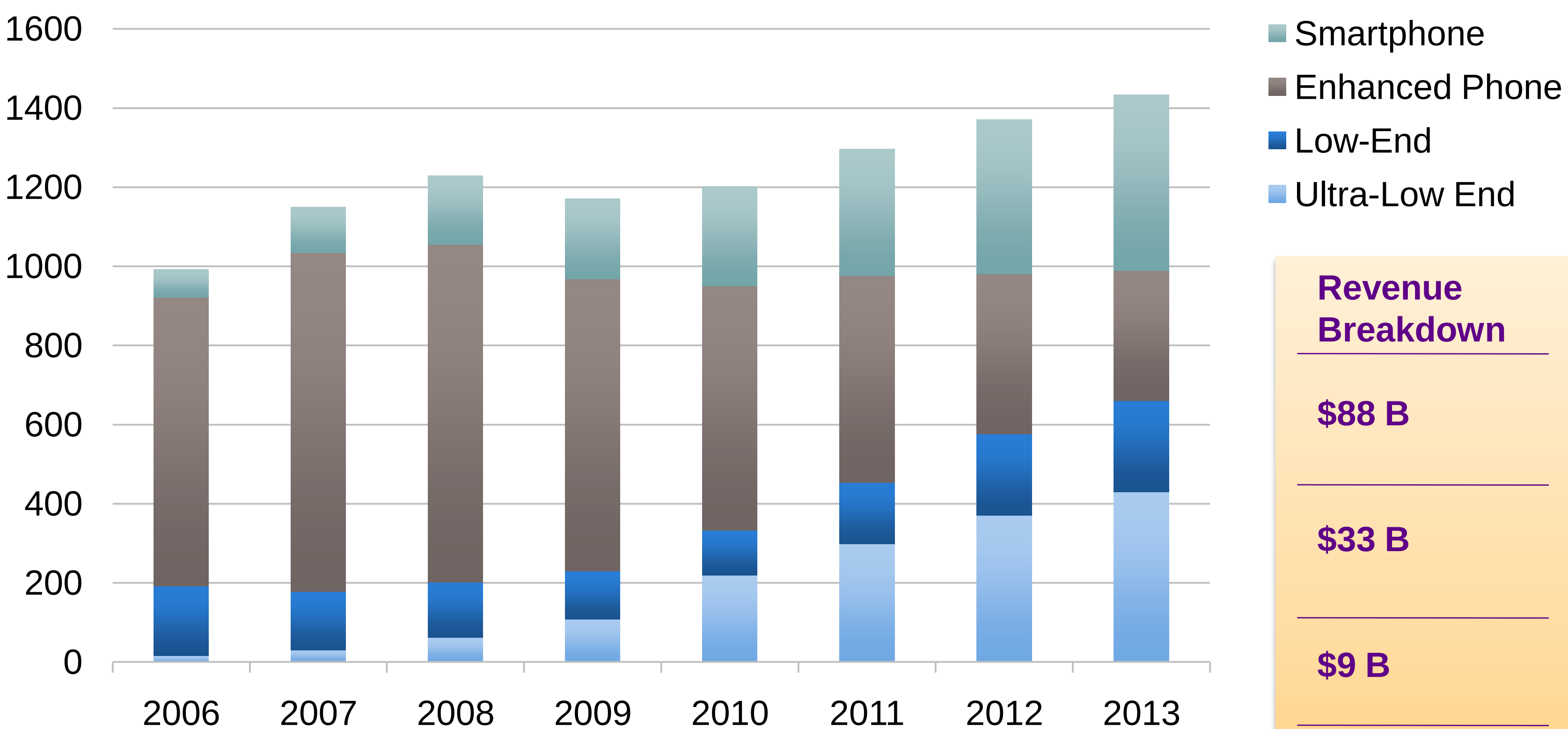


GSM shipments declining since 2008
3G handset shipments to exceed GSM in 2010
By 2013, 3G handset shipments will approach ~1 billion

Note: 3G includes CDMA2000, WCDMA and TD-SCDMA
* Shipments refer to sell-through numbers from Informa and Yankee
Sources: Average of Yankee Group : Global Mobile Device Monitor/Forecast (Oct09), Informa Telecoms and Media (Oct'09)

Global Handset Demand Remains Strong Across Multiple Segments

NEW HANDSET SEGMENTATION (MILLIONS)



Revenue Breakdown

$88 B

$33 B

$9 B

$9 B

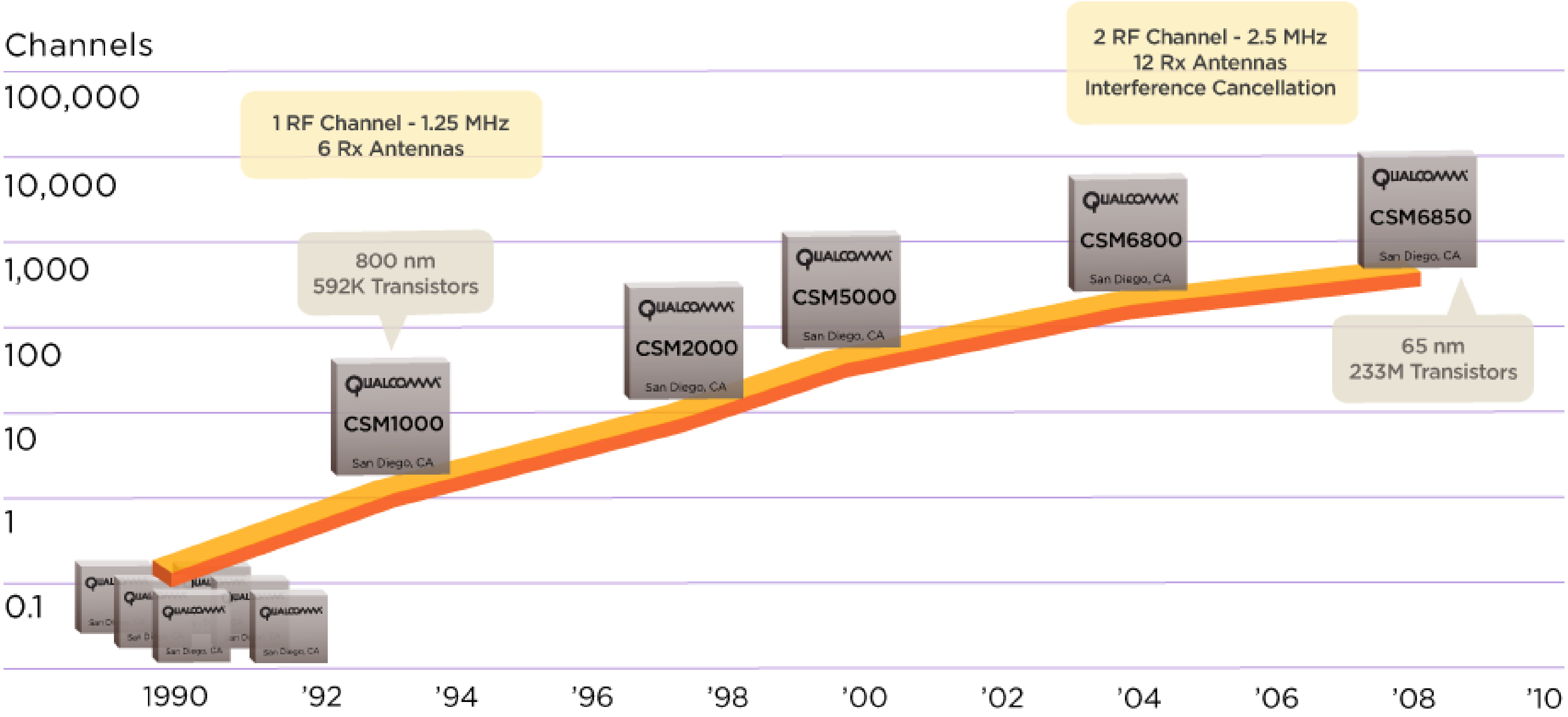
- Greater demand for infotainment and other rich media services that leverage mobile broadband
- Rapid growth of subscriber base in emerging markets

Source: ABI Research

How Did We Get This Far in Just 25 Years?

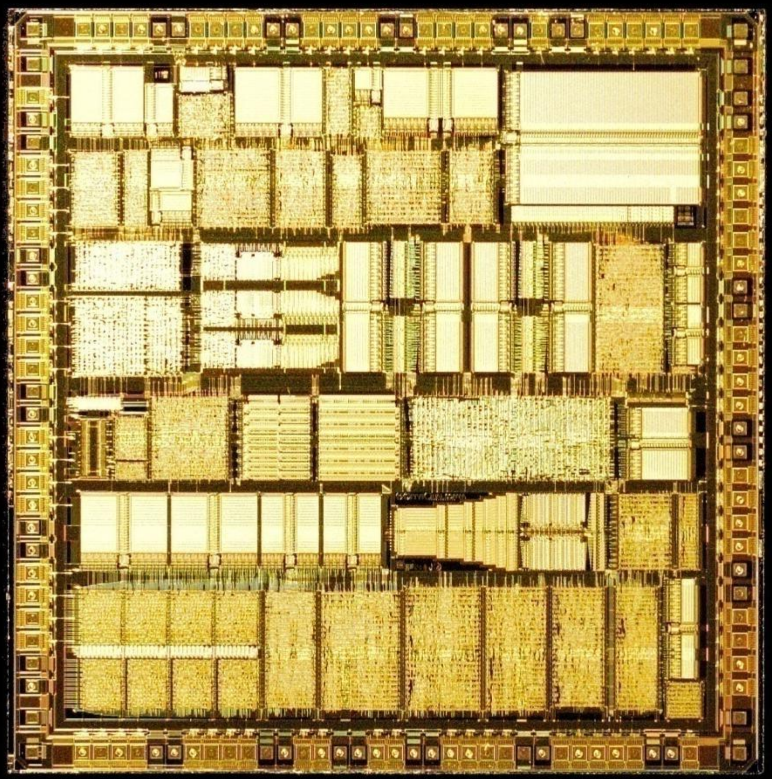
- Relentless progress in silicon technology
  - Higher integration, lower costs ($20 phones readily available in emerging markets), more capabilities.
- Technical advances in air interfaces
  - Higher efficiency for voice and data services, lower infrastructure capital costs.

An Example: CDMA Network Modems



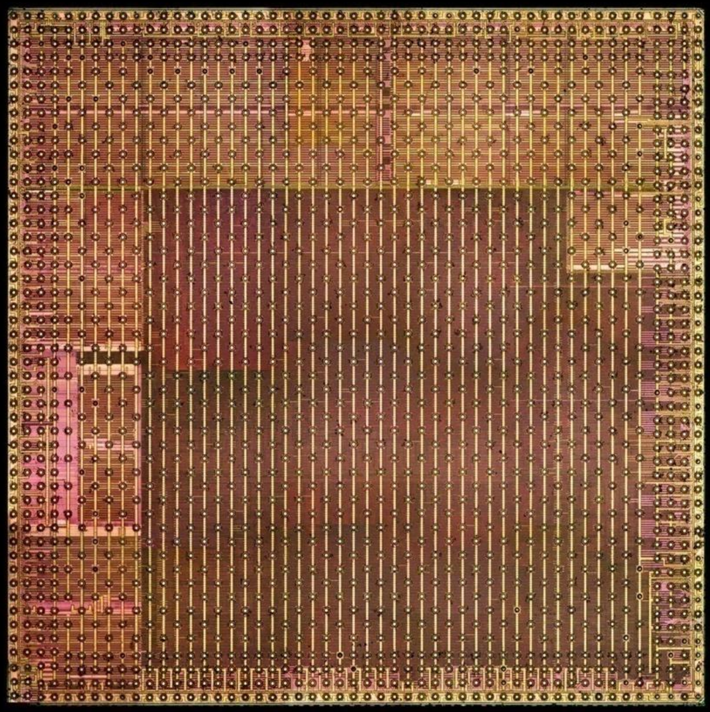
Network Modems: 14 Years Apart

1994



CSM 1.0
Die size: 10X10 mm, 0.8 um technology, 592K transistors

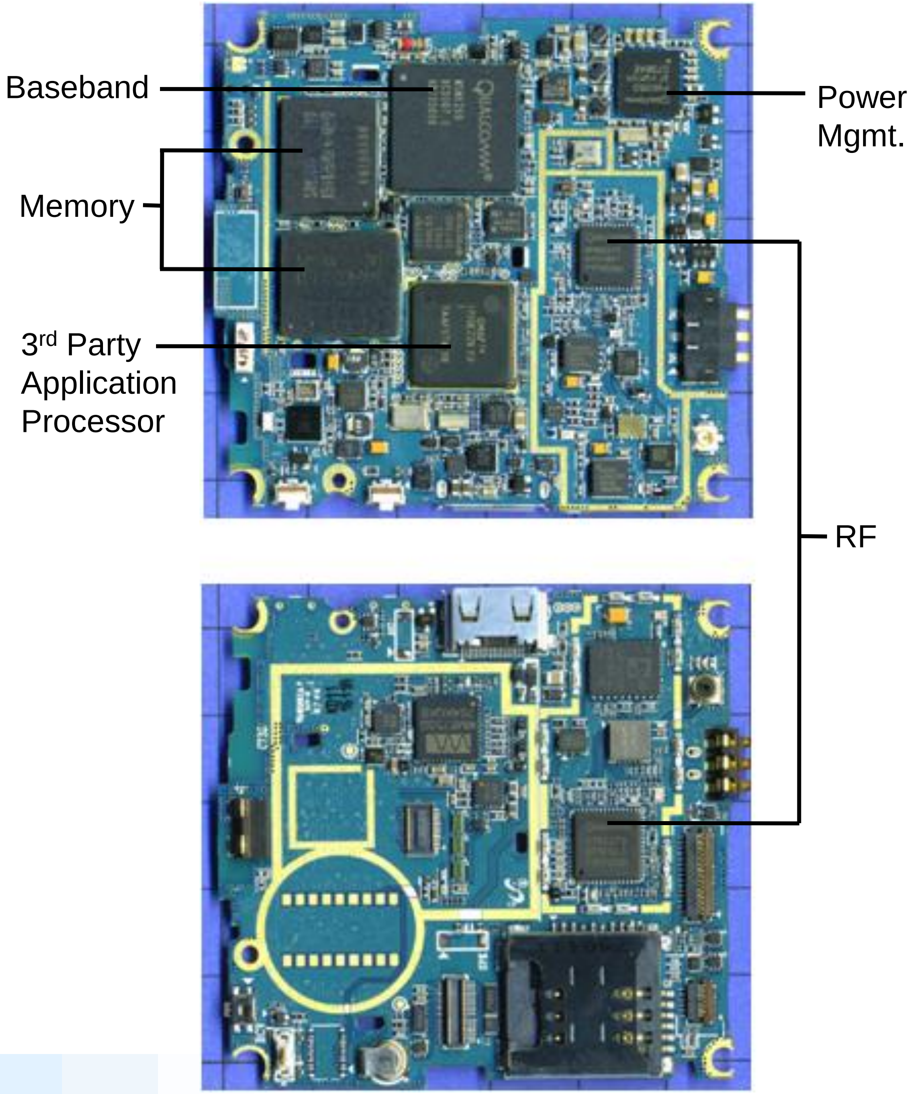
2008



CSM 6850
Die size: 9X9 mm, 65 nm technology, 233 million transistors

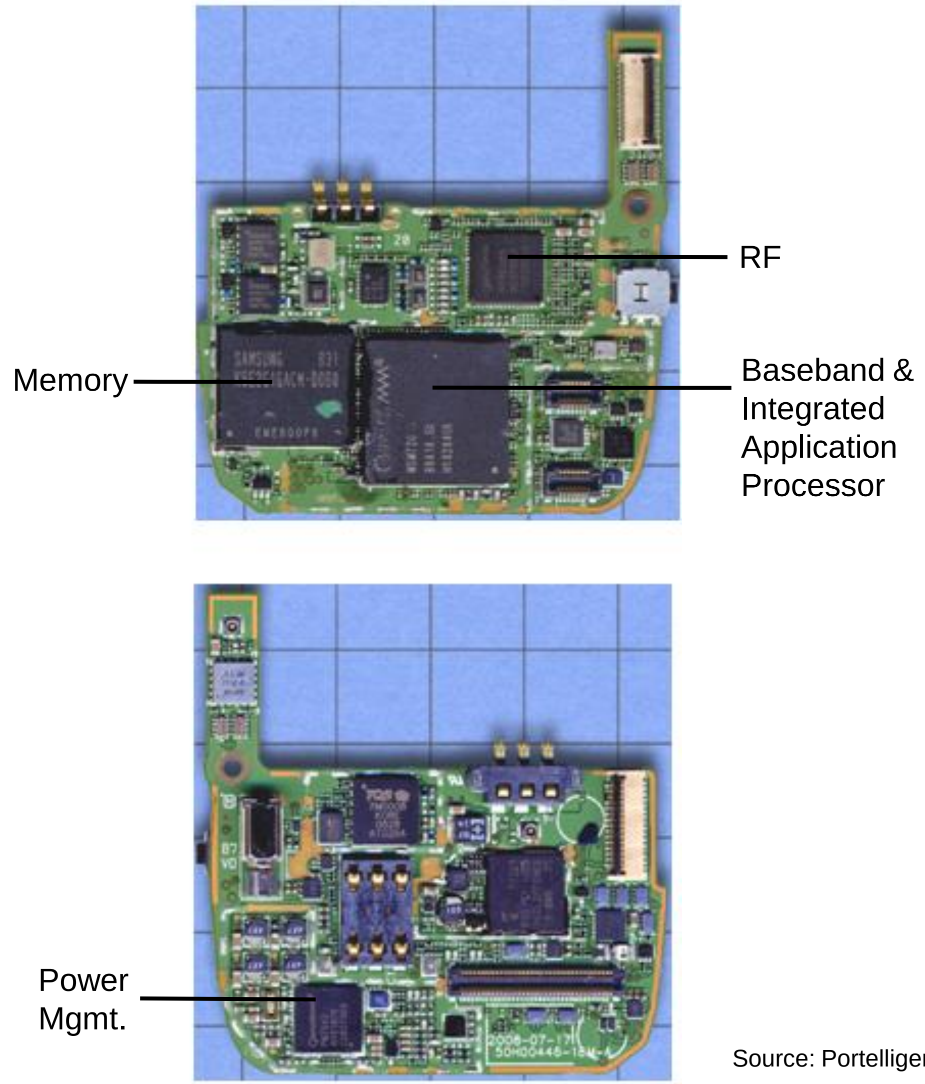
Simplifying Phone Design

MSM 6xxx Phone



MSM 7xxx Phone

HTC G1

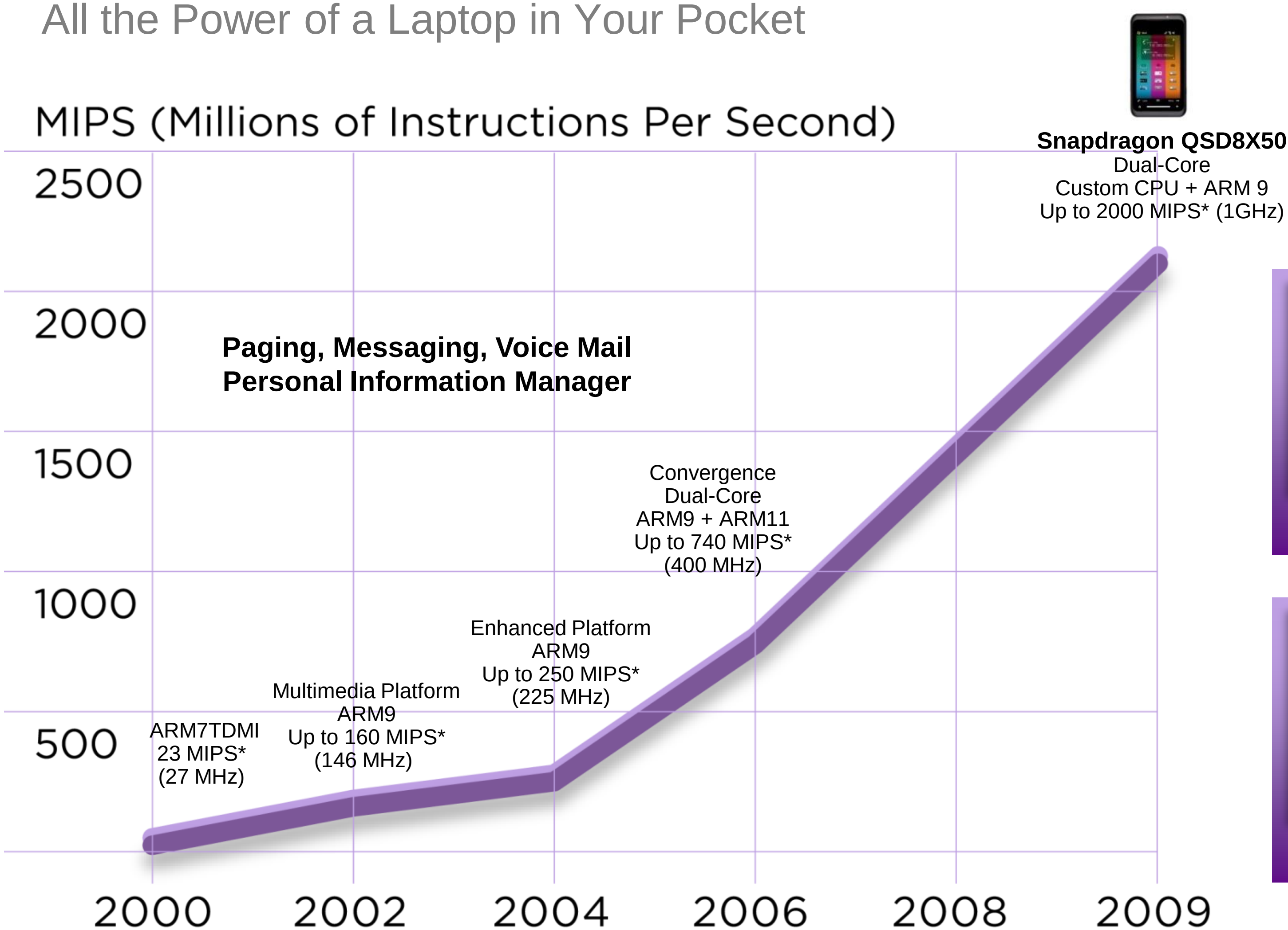


Source: Portelligent

Mobile Processing Power – Changing the Mobile Device

snapdragon™ by Qualcomm

All the Power of a Laptop in Your Pocket



Snapdragon QSD8650A

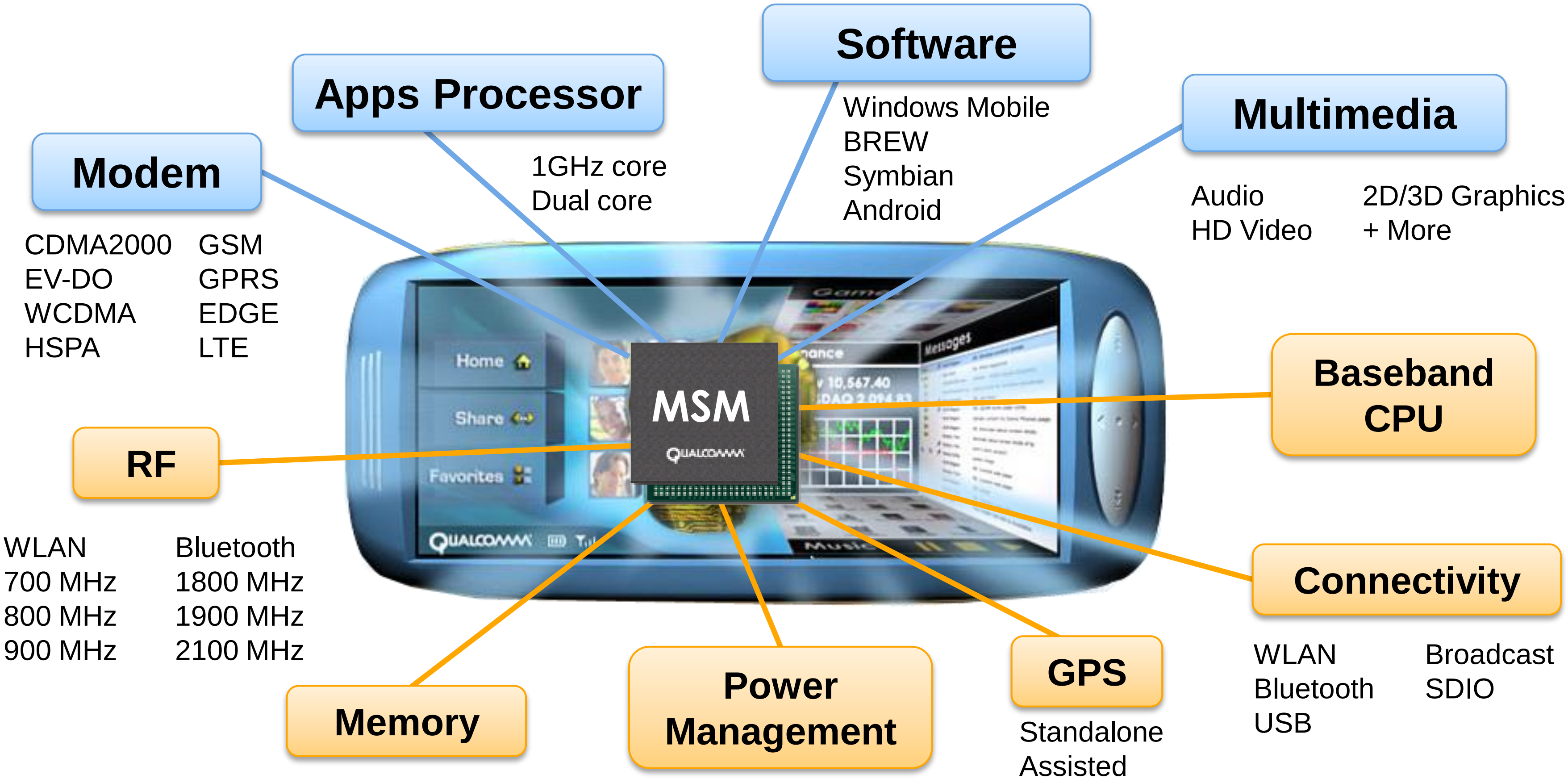
Dual-Core
Custom CPU + ARM 9
Up to 1.3GHz

Snapdragon QSD8672

Dual-Core
2X Custom CPU + ARM 9
Up to 1.5GHz

* Dhrystone 2.1

Chipset Business Evolving to System Business



Integration is key to driving advanced functionality to mass market

Creating New Mobile, Computing and CE Device Categories

snapdragon™
by Qualcomm

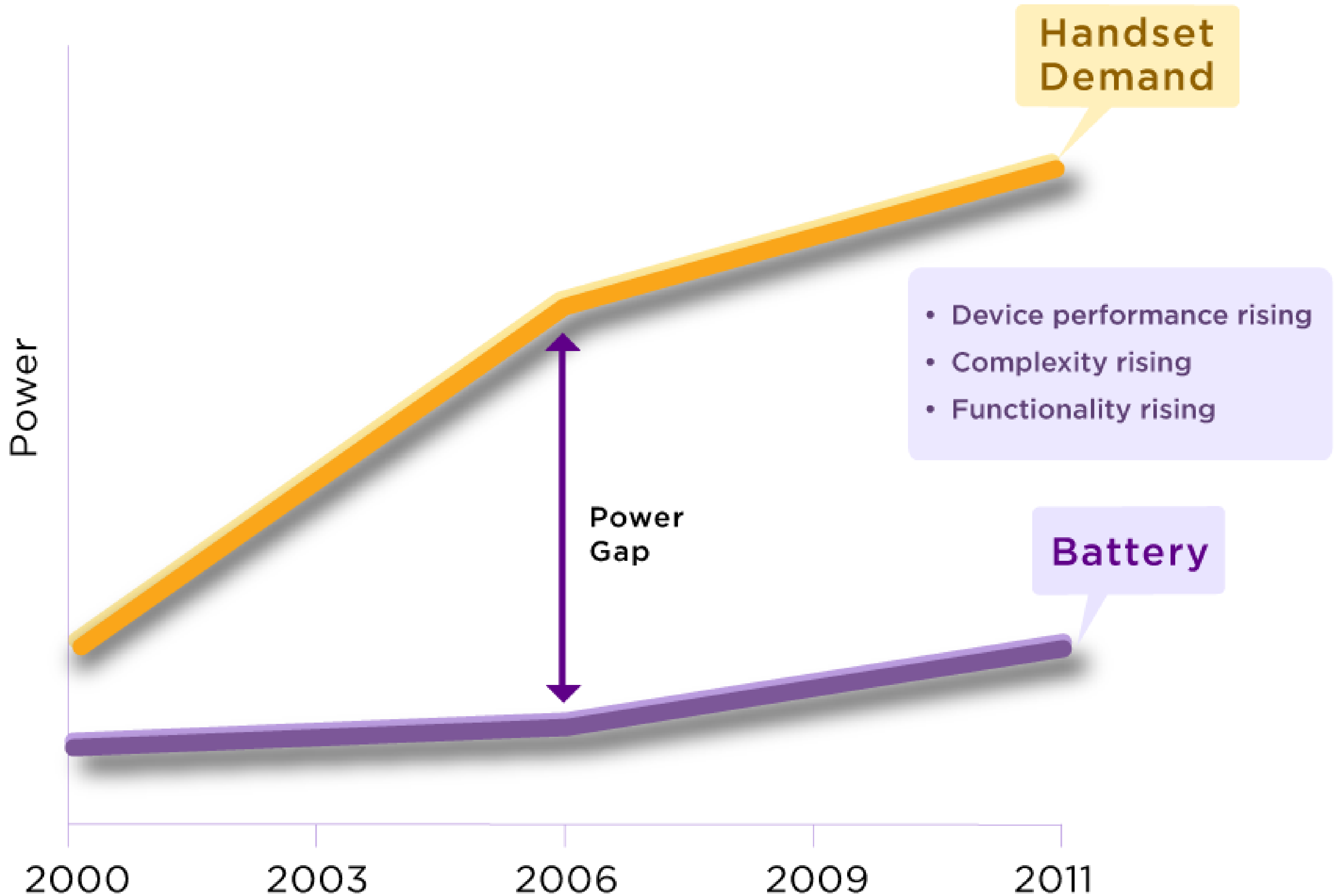
Always-On Connectivity

All-Day Battery Life

Instant On
(NO standby/sleepstates)

Location Aware

Challenge: Battery Technology is Falling Behind



Source: Battery Technology & Power Management Conference, Vancouver, August 2005 – Stuart Robinson, Strategy Analytics, Ltd.

Focus on Improving Battery Life

mirasol

Low-power
consumption display

snapdragon™
by Qualcomm

1+Ghz processing power
with low power consumption

eZone Universal Wireless Charging Technology

Charge Multiple Electronic Devices Safely, Wirelessly & Simultaneously

Wireless Power Landscape

Near Field Magnetic Resonance

- Short to medium range
- Designed to meet SAR compliance
- Does not need perfect alignment

Conductive Mat

- Needs electrical contacts

Inductive Coupling

- Short range
- Requires perfect alignment

Far-field Magnetic Resonance

- Long range
- Low efficiency
- Safety concerns

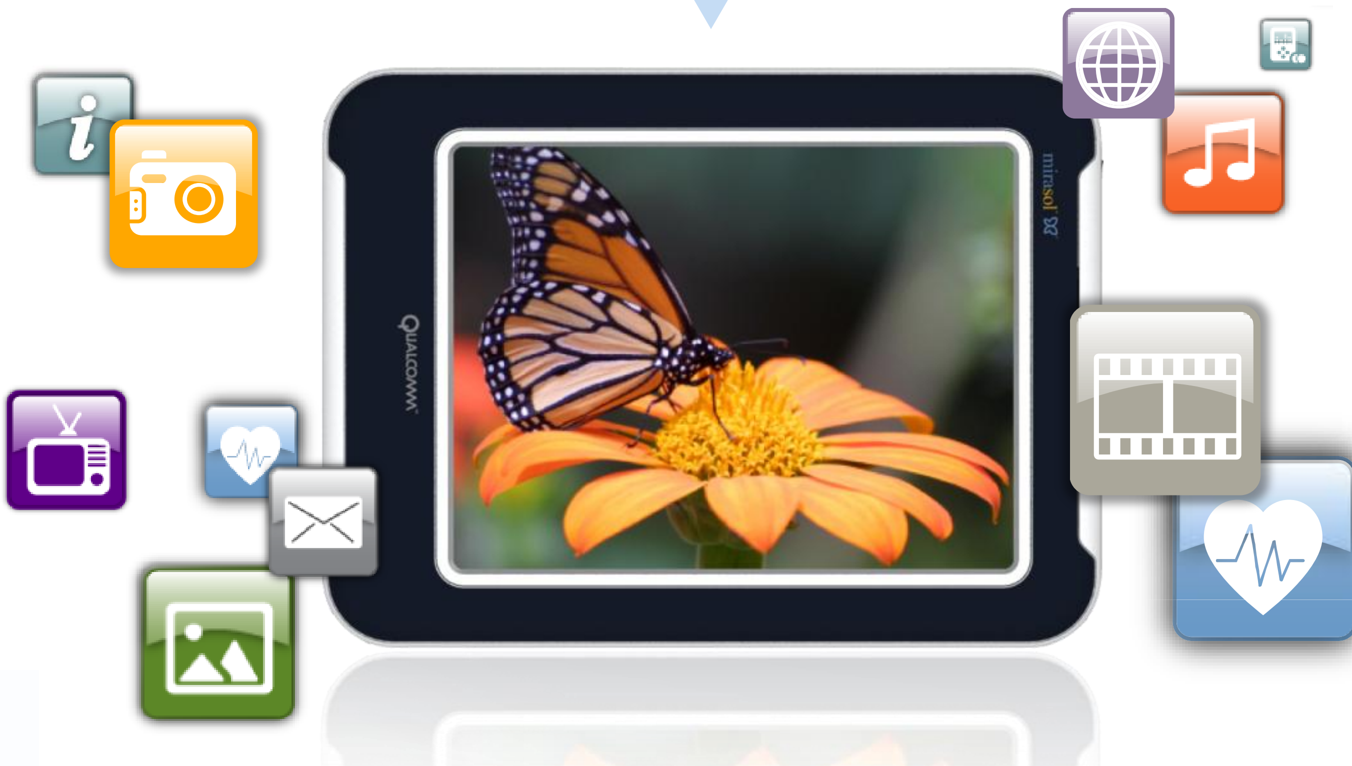
The Display: Where Convergence Lives

mirasol® DISPLAYS

10-100x More Efficient Than LCD

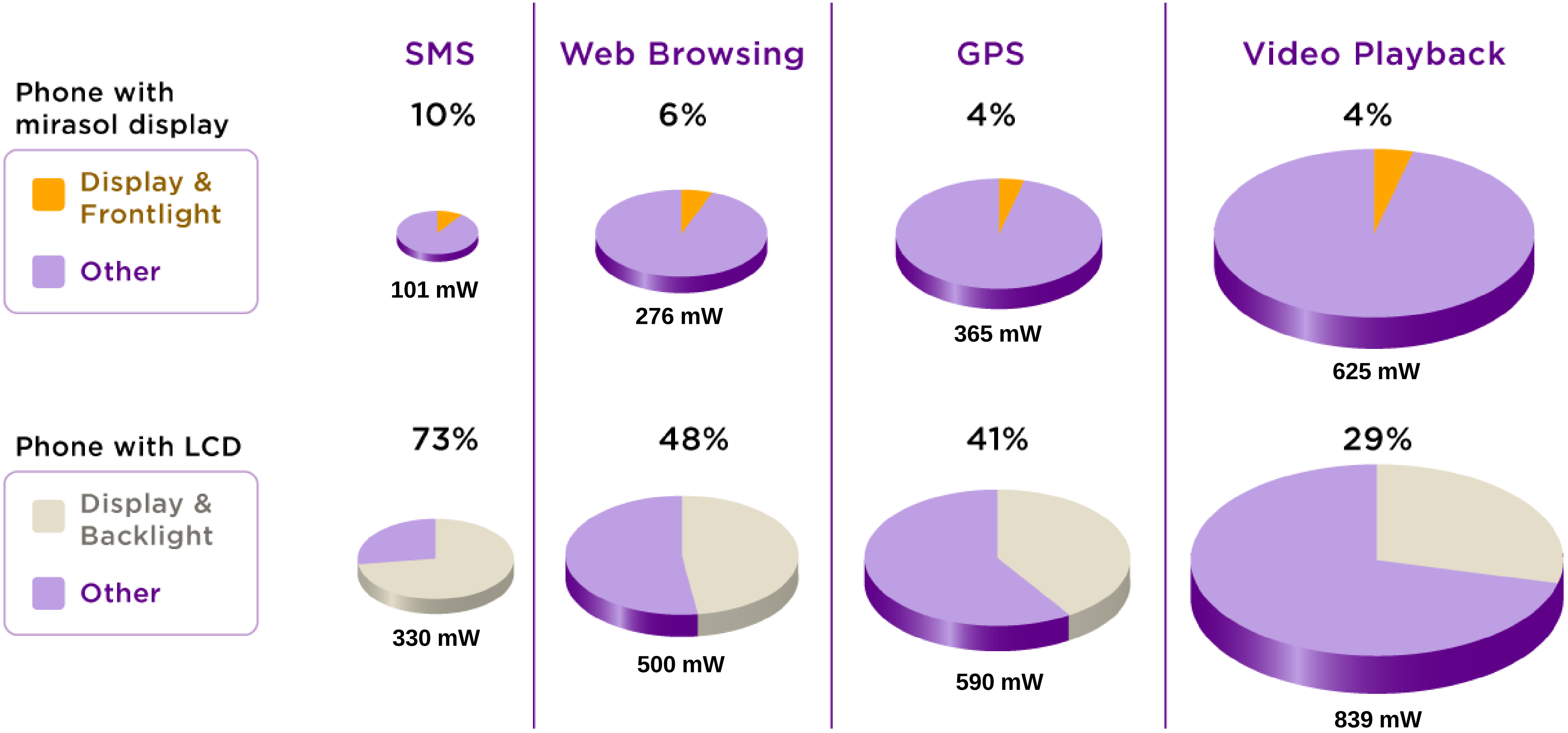
Visible Outdoors

Full Color & Video Capable



mirasol Displays Provide Considerable Power Savings Over LCD

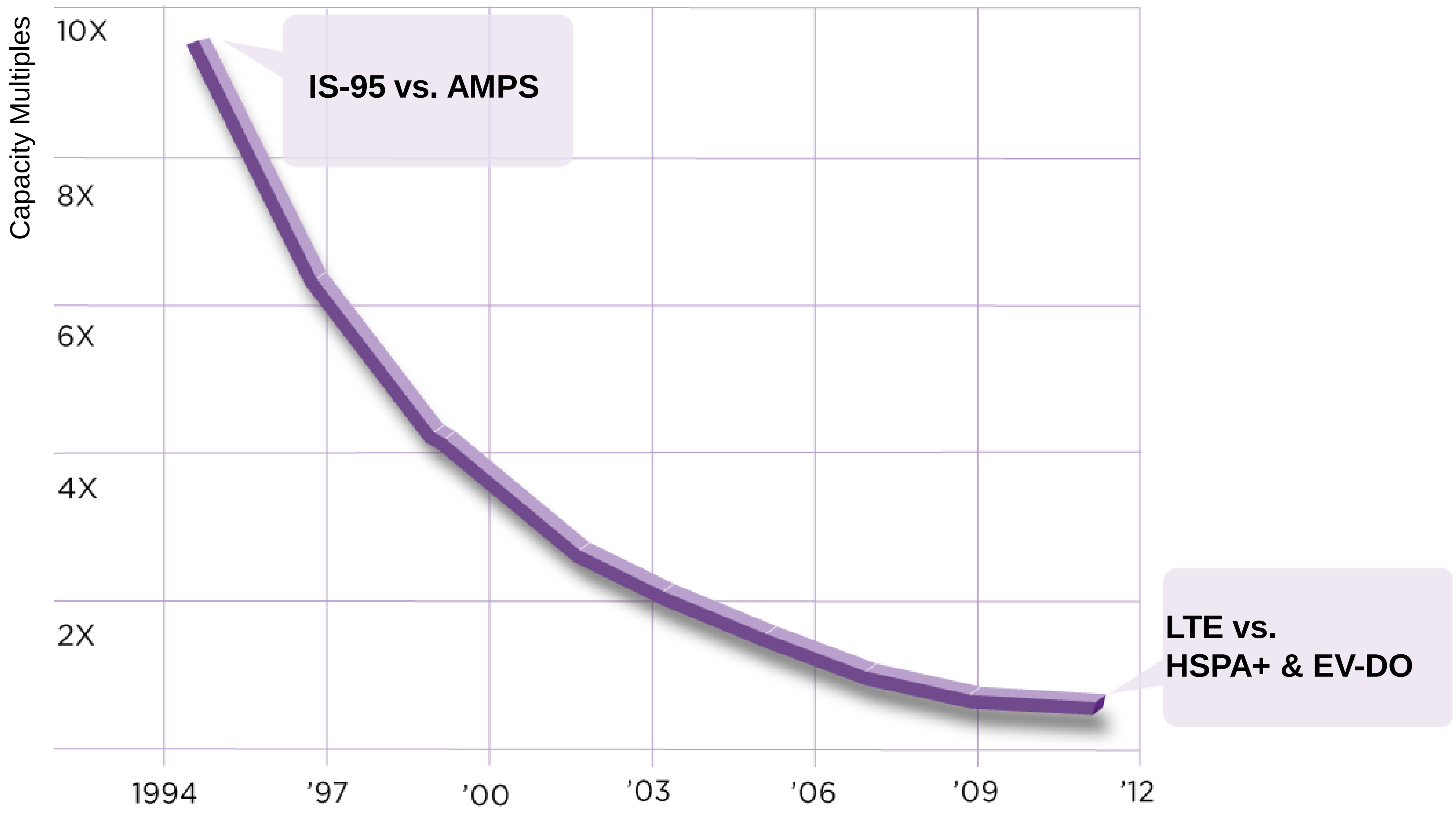
Display Power Consumption by Application



Source: Qualcomm Labs

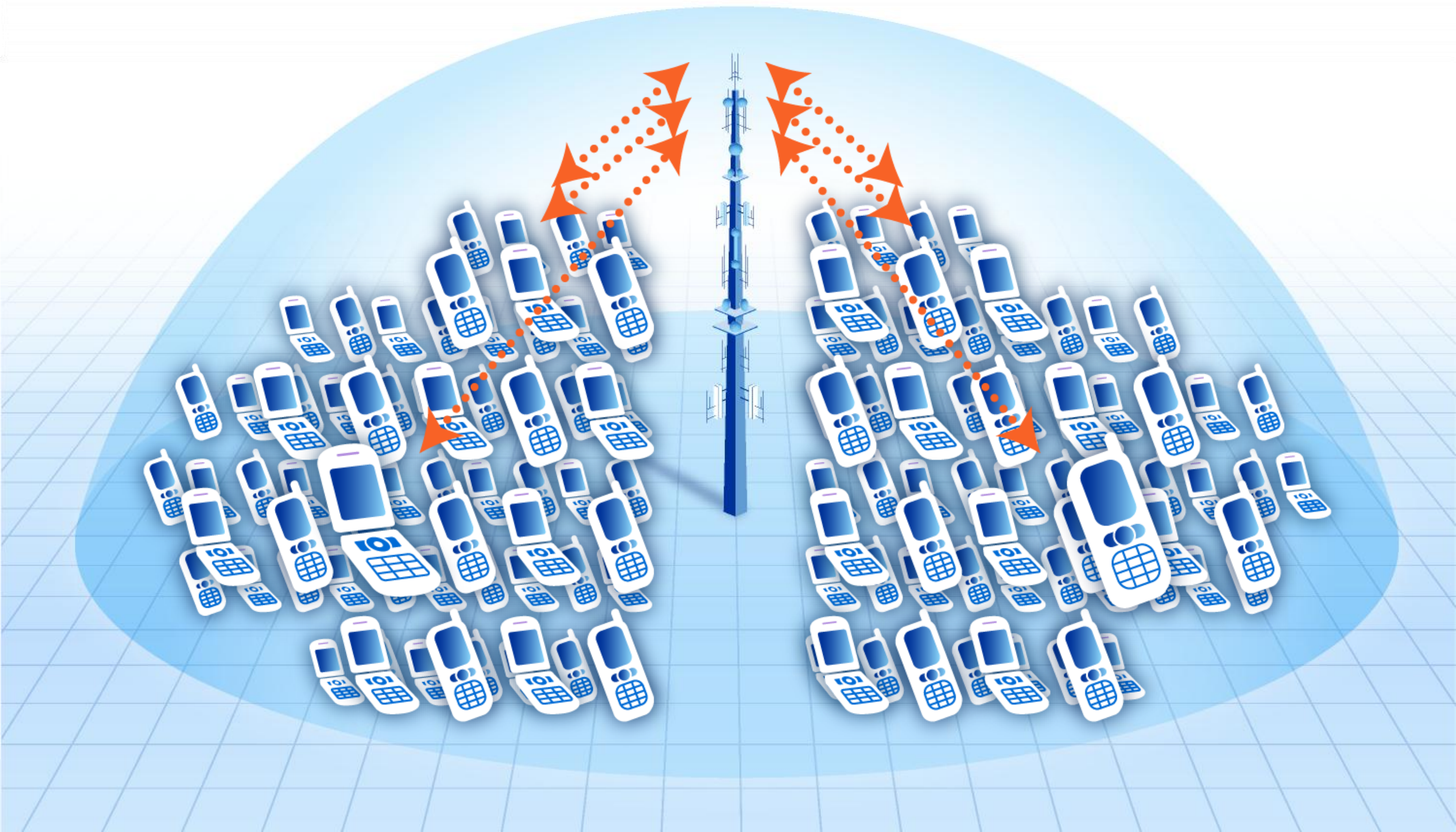
Air Interface Evolution

Spectral Efficiency: Significant gains so far, but reaching theoretical Limits

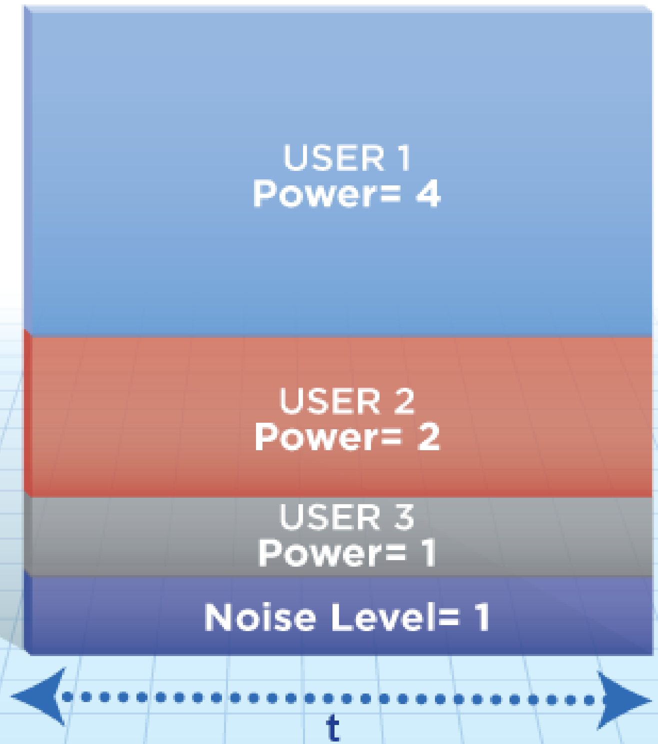


Source: Qualcomm simulation and analysis

Approaching Theoretical Limits - Successive Interference Cancellation



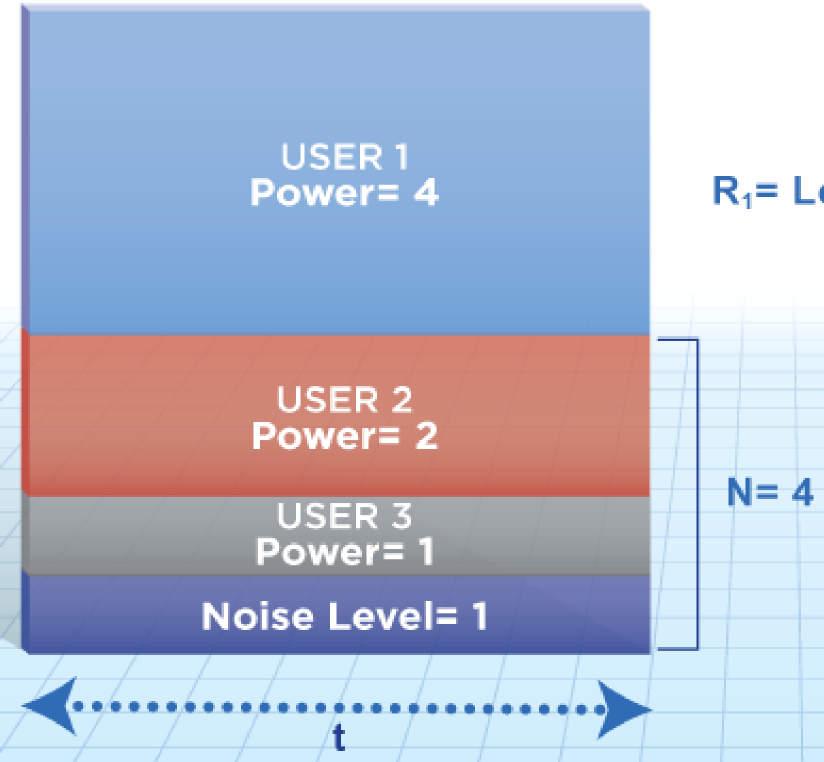
SIC Achieves Capacity
(e.g. equal rates, Viterbi IEEE JSAC May 1990)



$$R_1+R_2+R_3 <= \text{Log}_2\left(1+\frac{P_1+P_2+P_3}{N}\right)$$

$$R_1+R_2+R_3 <= \text{Log}_2\left(1+\frac{4+2+1}{1}\right) = 3\text{bps/HZ}$$

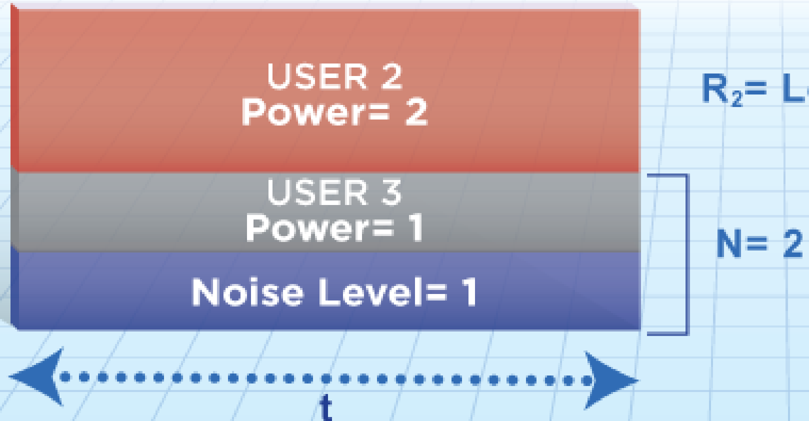
Interference Cancellation in Action



$R_1 = Log_2(1+P_1/N) \rightarrow R_1 = Log_2(1+4/4) = 1bps/Hz$

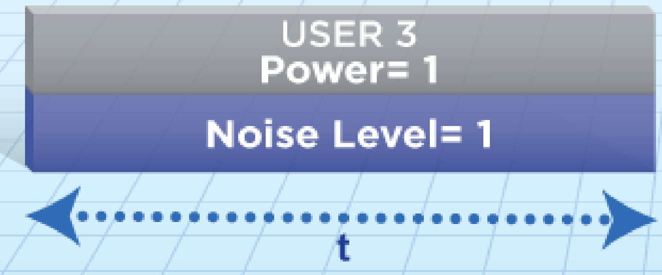
$$R_1+R_2+R_3 <= Log_2(1+\frac{4+2+1}{1}) = 3bps/Hz$$

Interference Cancellation in Action



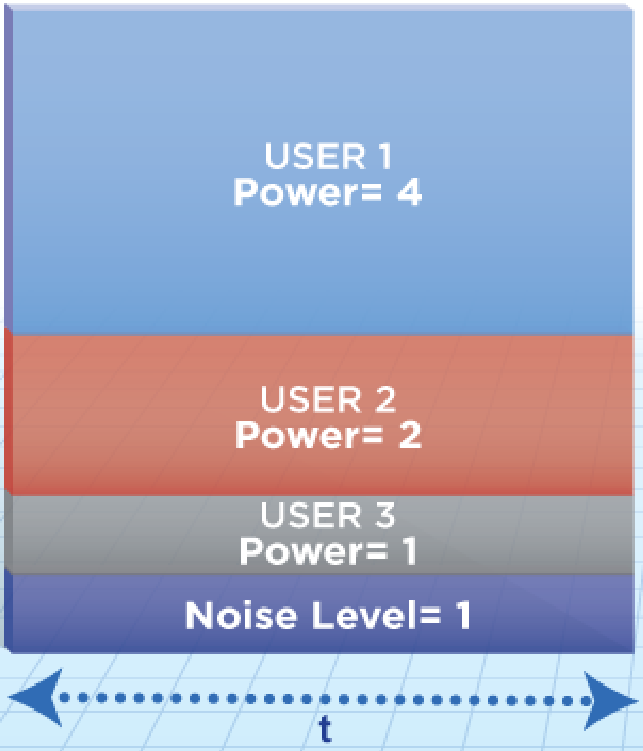
$R_2 = Log_2(1+P_2/N) \rightarrow R_2 = Log_2(1+2/2) = 1bps/Hz$

Interference Cancellation in Action



$R_3 = Log_2(1+P_3/N) \rightarrow R_3 = Log_2(1+1/1) = 1bps/Hz$

Interference Cancellation in Action



$$R_1+R_2+R_3 <= Log_2(1+\frac{4+2+1}{1}) = \text{3bps/Hz}$$

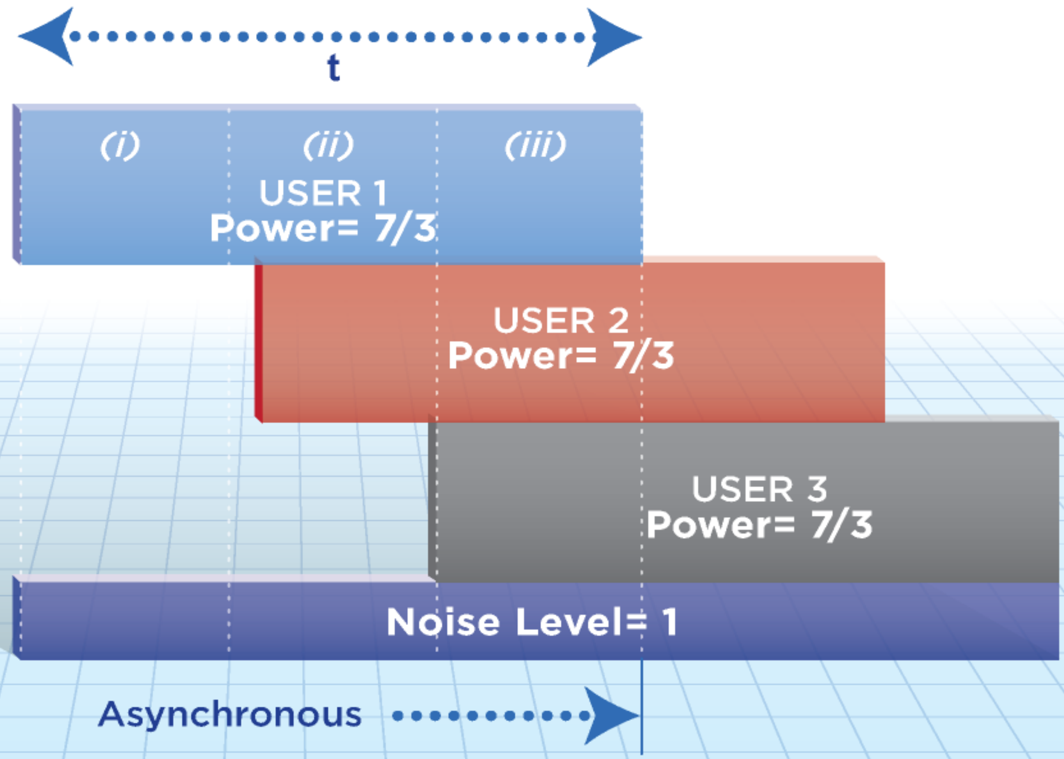
$$R_1+R_2+R_3 <= Log_2(1+\frac{P_1+P_2+P_3}{N})$$

Achieves sum rate capacity shown by Dr. Viterbi

$$R_1+R_2+R_3 = 1+1+1 = \text{3bps/Hz}$$

Asynchronous Transmissions & Frame Staggering

- Packets see interference only from future packets of other users
- Equal rates achieved with equal power and uniform delay profile



$$\text{User Cap}= \left[\frac{1}{3}\cdot \text{Log}_2\left(1+\frac{7/3}{1}\right) + \frac{1}{3}\cdot \text{Log}_2\left(1+\frac{7/3}{7/3+1}\right) + \frac{1}{3}\cdot \text{Log}_2\left(1+\frac{7/3}{2\cdot 7/3+1}\right)\right]$$

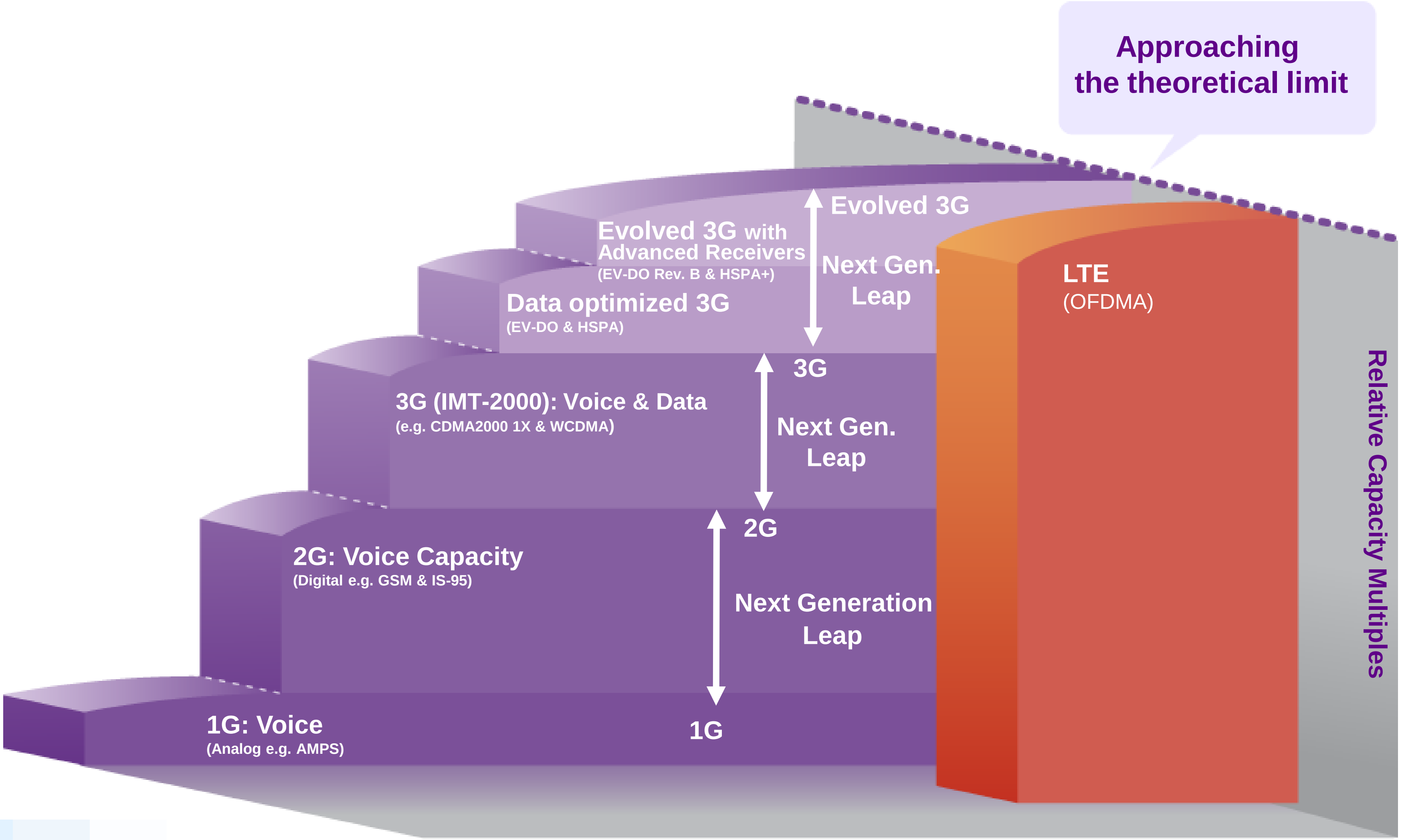
1bps/Hz per user

Achieves sum rate capacity

SIC Had Been Sitting on the Bookshelf…

- Until the perfect storm arrived about 3 years ago…
- Realization that sum rate capacity could be achieved without the need of synchronous transmissions and exponential power distribution
- Process technology node transitions
- Development of embedded memory technology allowed large amounts of on-chip memory
- Thus we had the ingredients and the recipe, all that was left was a lot of hard work…

Radio Link Improvement is Slowing, What Is Next?



Two Directions

- A. Continue improvements in spectral efficiency with tighter coordination amongst base stations
- B. Change the metrics: Focus on increasing density of deployment to optimize spectral efficiency/area.

A. Coordinated Transmissions

- Think of entire deployment as a large broadcast channel
  - optimal capacity region achievable w/ TX precoding and DPC
  - performance nearly achievable w/ linear multi-point equalizer.

Channel matrix *MPE matrix*

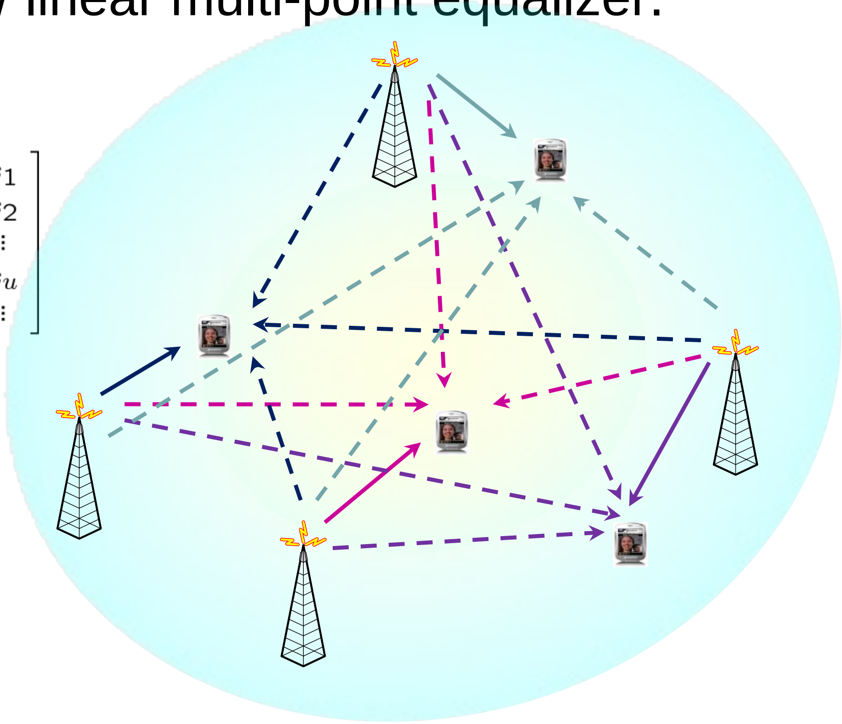
$$\begin{bmatrix} \boldsymbol{H}_{1,1} & \boldsymbol{H}_{1,2} & \cdots & \boldsymbol{H}_{1,c} & \cdots \\ \boldsymbol{H}_{2,1} & \boldsymbol{H}_{2,2} & \cdots & \boldsymbol{H}_{2,c} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \ddots & \ddots & \cdots \\ \boldsymbol{H}_{u,1} & \boldsymbol{H}_{u,2} & \cdots & \boldsymbol{H}_{u,c} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \end{bmatrix} \begin{bmatrix} \boldsymbol{W}_{1,1} & \boldsymbol{W}_{1,2} & \cdots & \boldsymbol{W}_{1,u} & \cdots \\ \boldsymbol{W}_{2,1} & \boldsymbol{W}_{2,2} & \cdots & \boldsymbol{W}_{2,u} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \ddots & \ddots & \cdots \\ \boldsymbol{W}_{c,1} & \boldsymbol{W}_{c,2} & \cdots & \boldsymbol{W}_{c,u} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_u \\ \vdots \end{bmatrix}$$

Channel from Cell$_c$ to UE$_u$

Packet to UE$_u$

Signal-to-leakage ratio (SLR)

$$\boldsymbol{W}_{:,u} = \arg \max_{\|\boldsymbol{w}\|^2 = P_s} \frac{|\boldsymbol{H}_{u,:}\,\boldsymbol{w}|^2}{1 + \sum_{u' \neq u} \left|\boldsymbol{H}_{u',:}\,\boldsymbol{w}\right|^2}$$



Major limiting factors for gain with Coordinated Transmission

- limited CSI (Channel State Information) accuracy: fundamental accuracy ⬄ overhead tradeoff

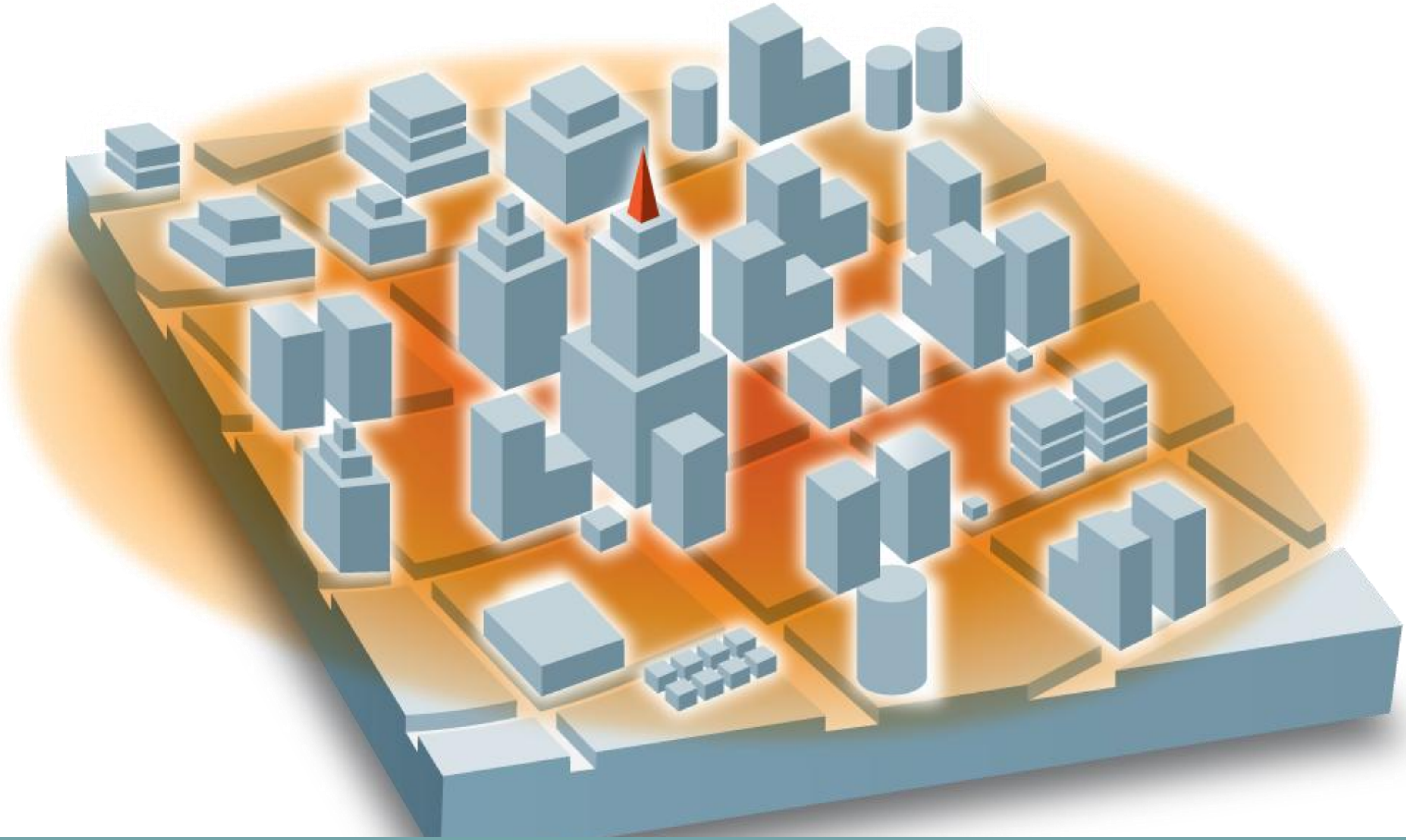
- Backhaul load with increasing number of cooperating cells.

Performance gains

UEs / cell	RX x TX	Statistics	Gain with coordinated transmission
5	2x2	10%	**39%**
		50%	**32%**
		mean	**20%**
	2x4	10%	**96%**
		50%	**39%**
		mean	**26%**

Conclusion: Coordinated Transmission offers moderate gains with significant complexity

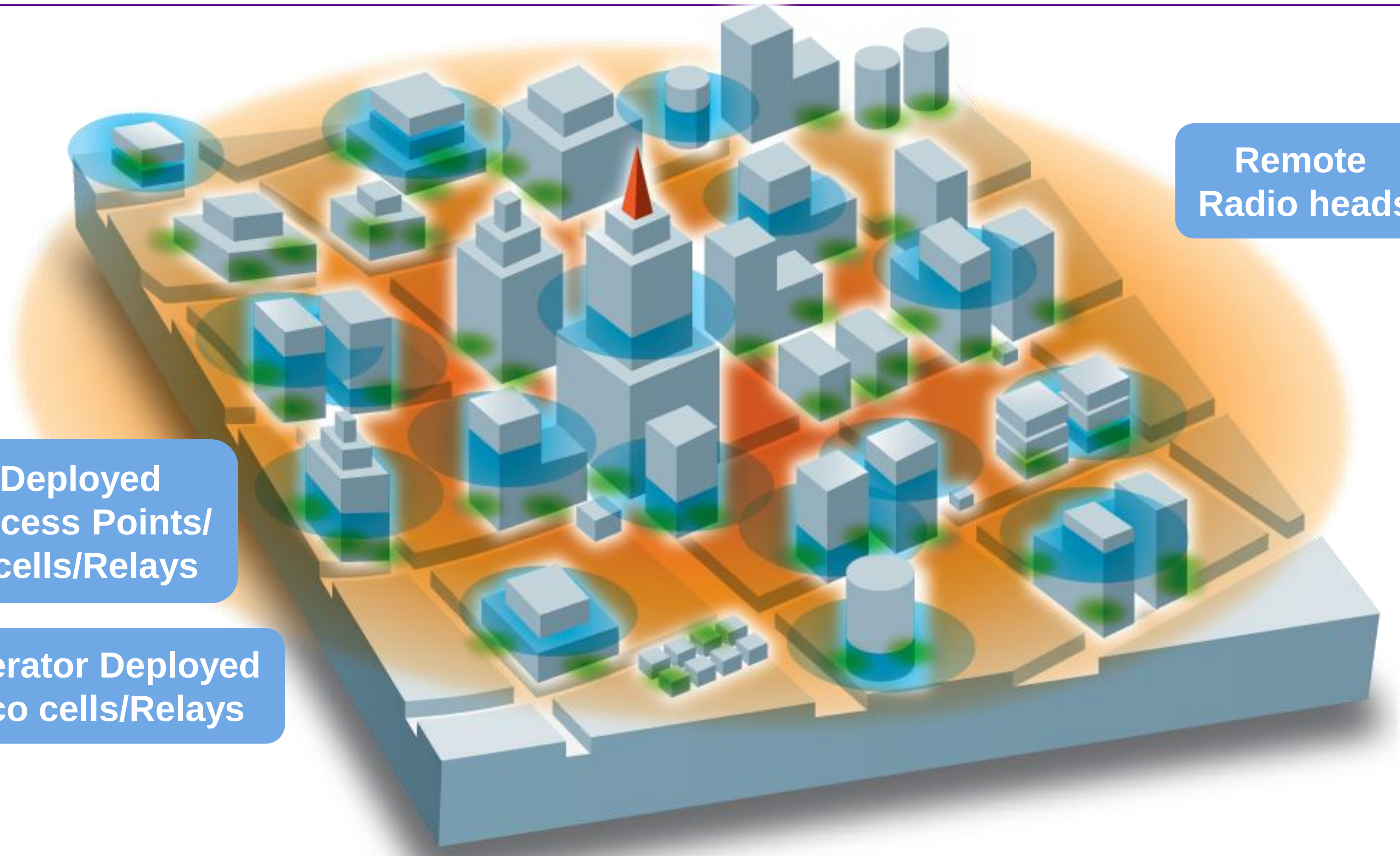
Traditional challenges to increasing deployment density



Macro network challenges to provide ubiquitous user experience

- ***Network Planning***
- ***Indoor coverage***
- ***Site acquisition***
- ***Network topologies change***

B. Bring Transmitter Closer to User – Heterogeneous Networks



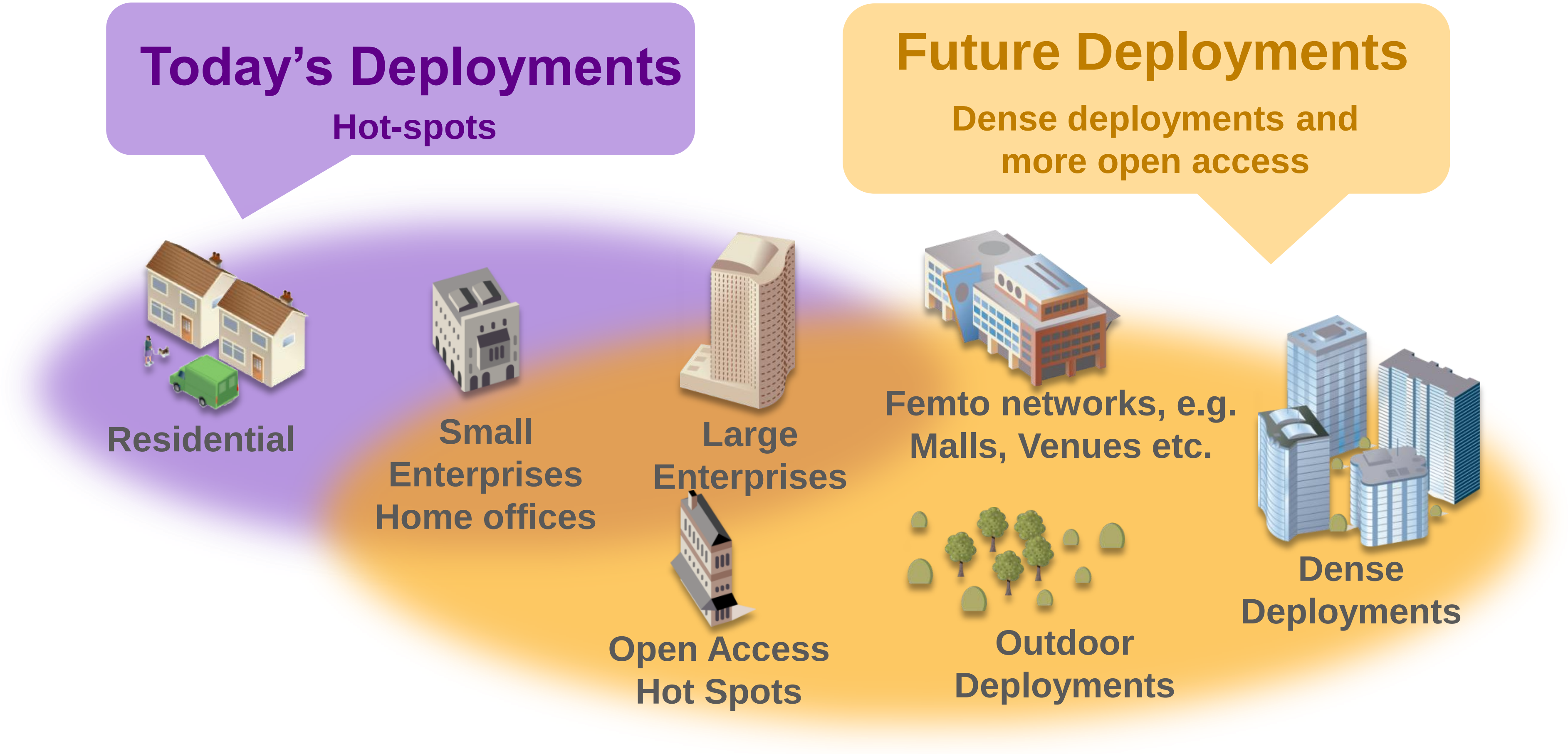
Remote Radio heads

User Deployed WiFi Access Points/ Femtocells/Relays

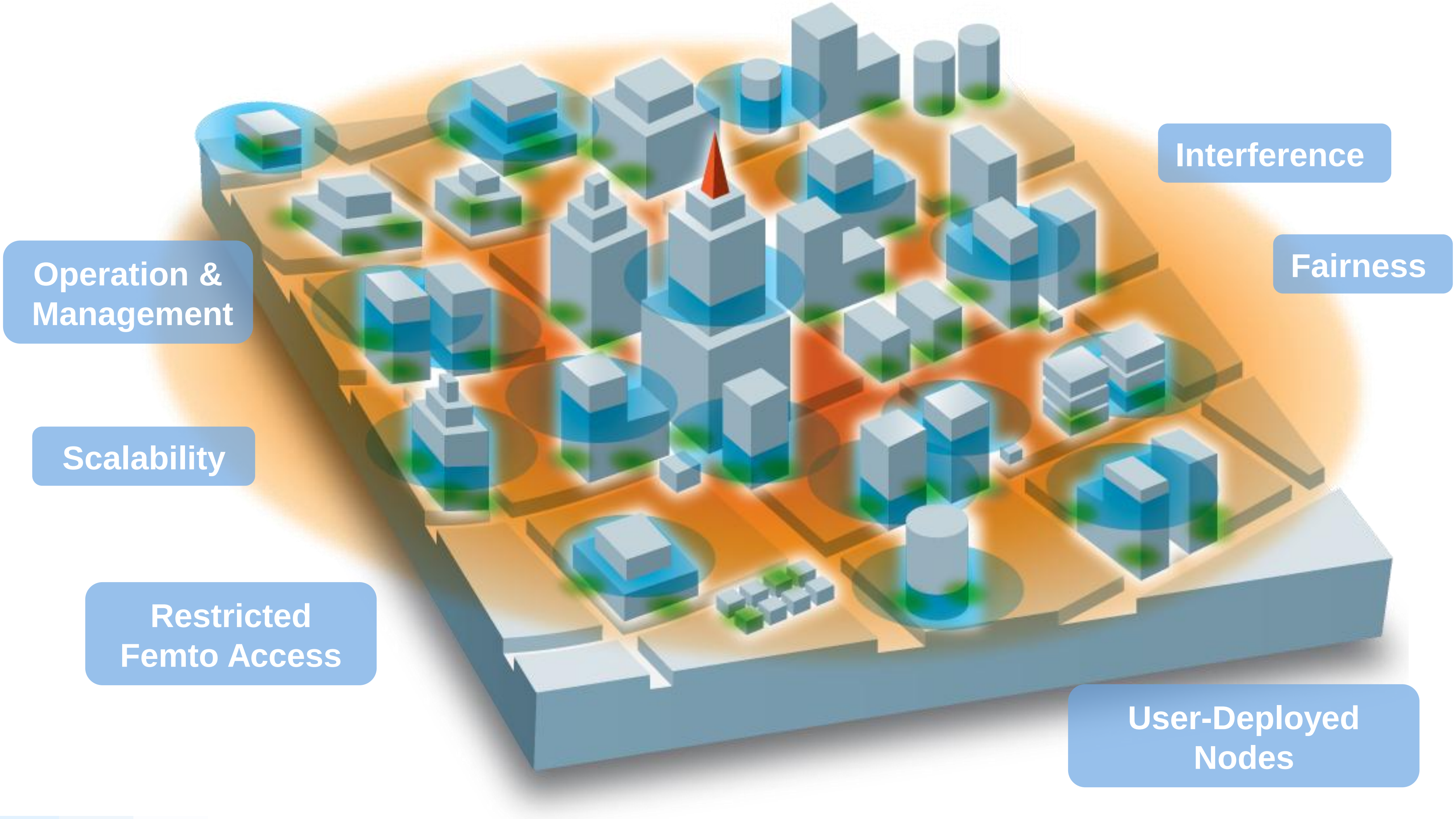
Operator Deployed Pico cells/Relays

Topology will provide gains beyond technology

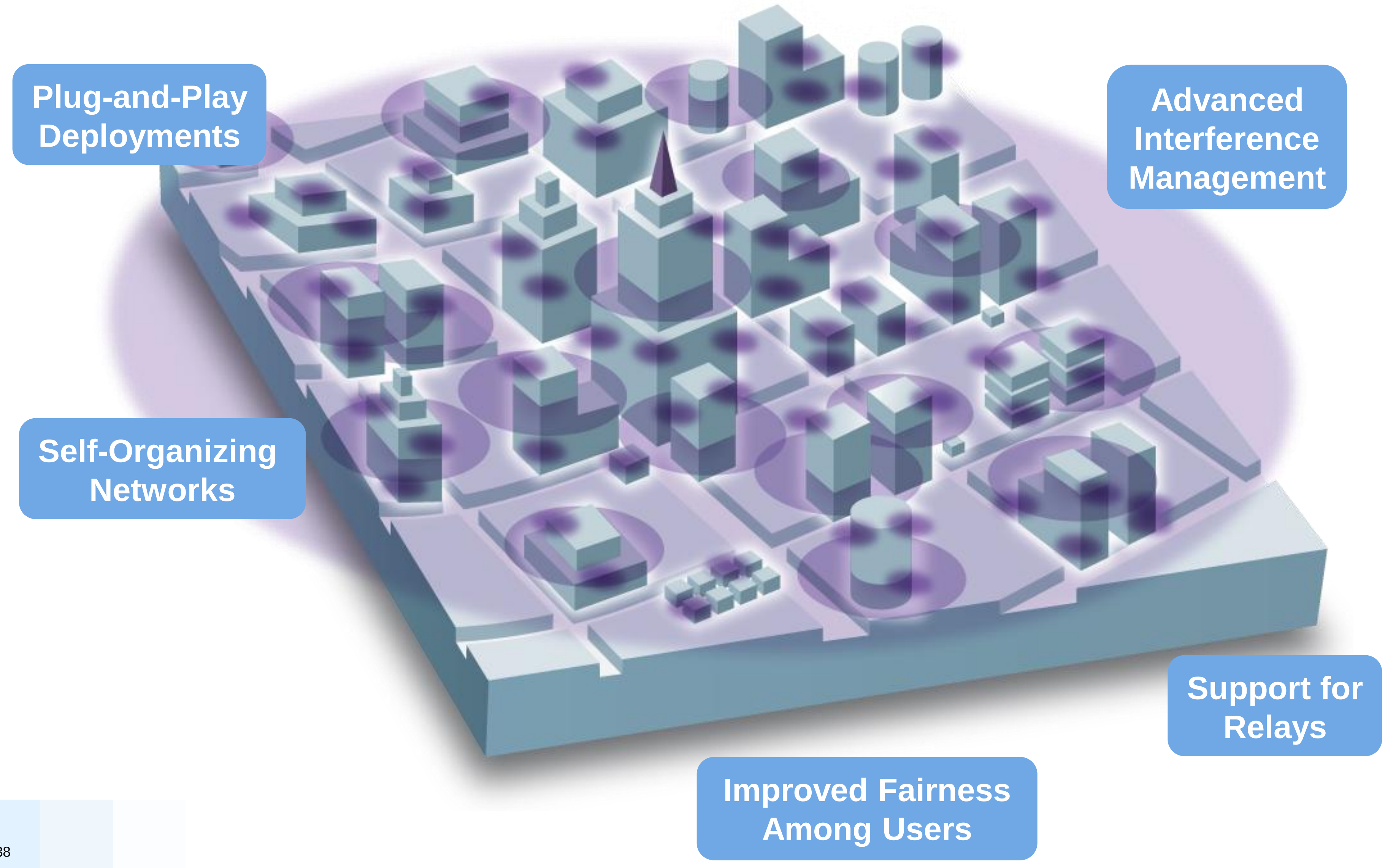
Deployment Model With Heterogeneous Networks



Heterogeneous Networks Impose Challenges

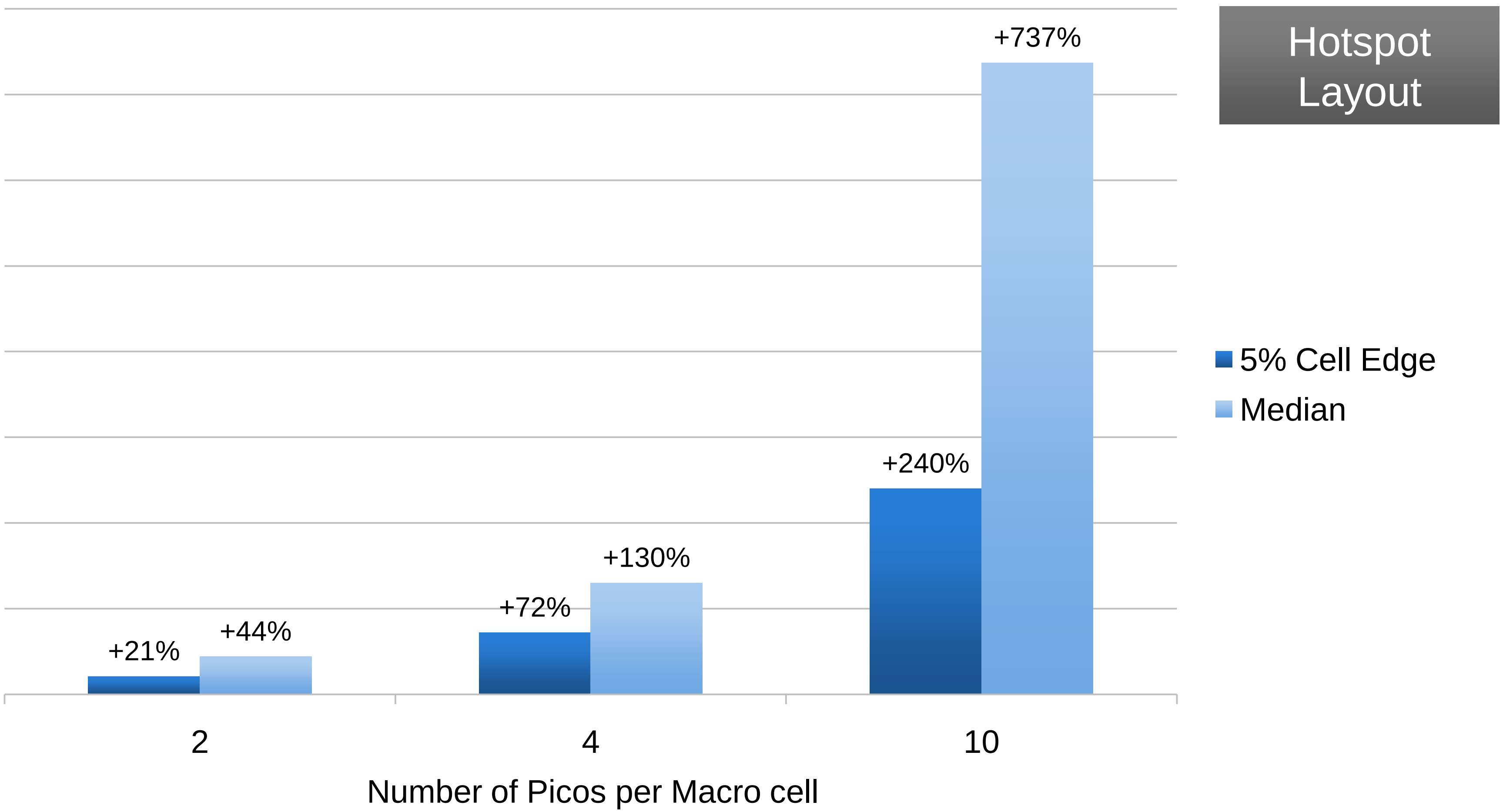


Techniques for Heterogeneous Networks



DL Improvements

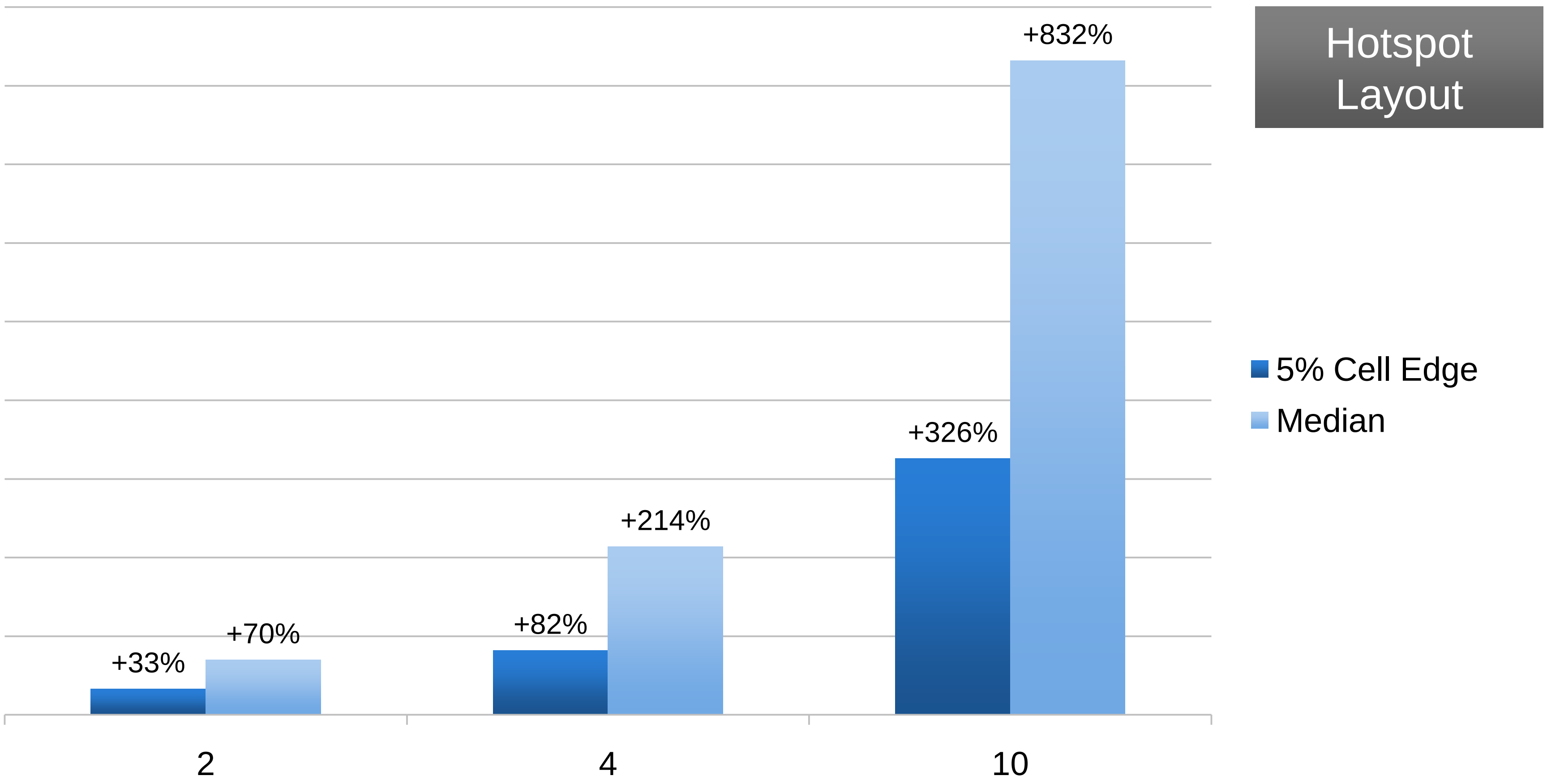
GAINS IN DL USER DATA RATE COMPARED TO MACRO-ONLY LTE



Based on proposed LTE-A evaluation methodology in R1-084026
Results from R1-090865; 10 MHz FDD, 2x2 MIMO UE, hotspot layout
Interlaces partitioned using X2-based adaptive algorithm

UL Improvements

GAINS IN UL USER DATA RATE COMPARED TO MACRO-ONLY LTE



Resource partitioning is based on a fixed ratio throughout the network
Based on proposed LTE-A evaluation methodology in R1-084026
Results from R1-090868; 10 MHz FDD, hotspot layout, single TX antenna UE
Interlaces partitioned using X2-based adaptive algorithm

Conclusion

- Continued growth in cell-phone penetration.
- Emergence of new class of ‘data-centric’ wireless devices.
- Battery technology not keeping pace, but innovative solutions are emerging.
- Traditional optimization in wireless technology reaching its theoretical limits.
- Topology, not technology, will provide the next leap in air interface capacity.