City-Wide Wi-Fi Mesh

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TROPOS networks

Building the Broadband Atmosphere

Outline

- Metro-scale Wi-Fi description
- True Broadband results in dense cells
- Mesh networking advantages
- Deployment examples
- Wi-Fi compared to 3G for broadband
- Conclusions

Home Wi-Fi

- Generally a single access point (AP) <$100
- Basic firewall and WEP key is good enough security
- Backhaul to internet is often cable or DSL connected directly to AP

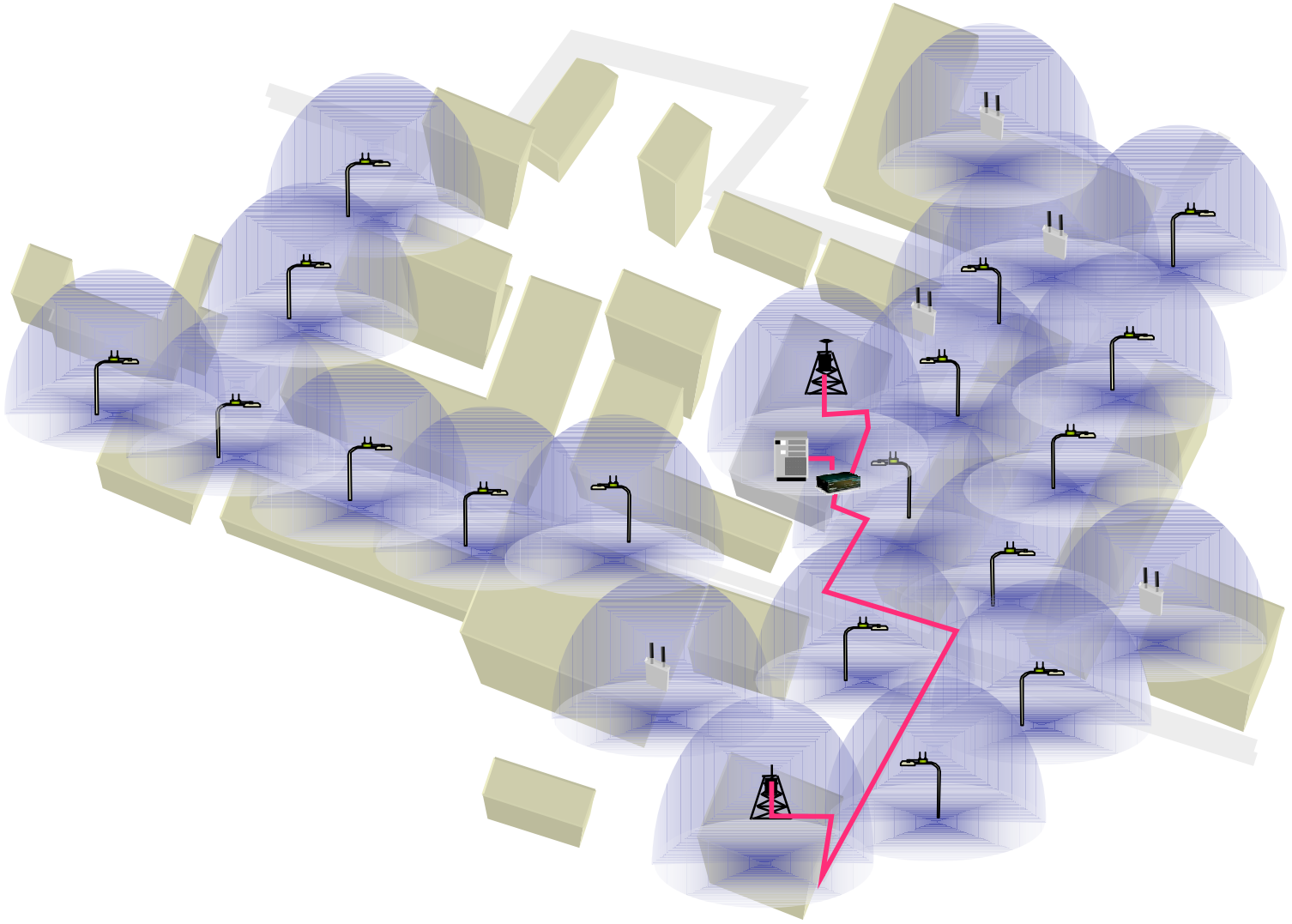
Enterprise Wi-Fi

- High capacity requirements
- Generally indoor environments
- Most (if not all) APs are connected back through a wired connection (e.g., switch)
- Most APs transmit at approx. 100mW
- Strong over-the-air and end-to-end security required
- 802.11a advantageous due to higher throughput, indoor environment, and less crowded airwaves

Hotspot Wi-Fi

- Examples: Starbucks, Hotels
- Provides access to individuals who bring 802.11 enabled device to the (generally) small area
- Often run w/ no security (no WEP)
- Users are directed to a captive portal to subscribe to a service plan

Metro-Scale Wi-Fi



Capacity per user: Cell size

	Cell Size (Miles)	Power (Watts)	Capacity per user (kbps)
Big-Stick (TV/Radio)	>10	~1,000,000	0
Cellular (telephony)	> 1	~100	~10 to 100
Dense-Cellular (Wi-Fi)	< 1	~1	>>1000

Capacity per user: Shannon's Law

Transmitter

Wireless Medium

Receiver

1. Bandwidth of the medium
2. Signal Power (*Receiver)*
3. Noise Power (*Receiver)*

Channel Capacity = Bandwidth x $\log_2(1 + \text{Signal/Noise})$

Capacity per user: SNR and Propagation

Broadband requires uniform signal >> noise everywhere
(≥ -90dBm for Wi-Fi)

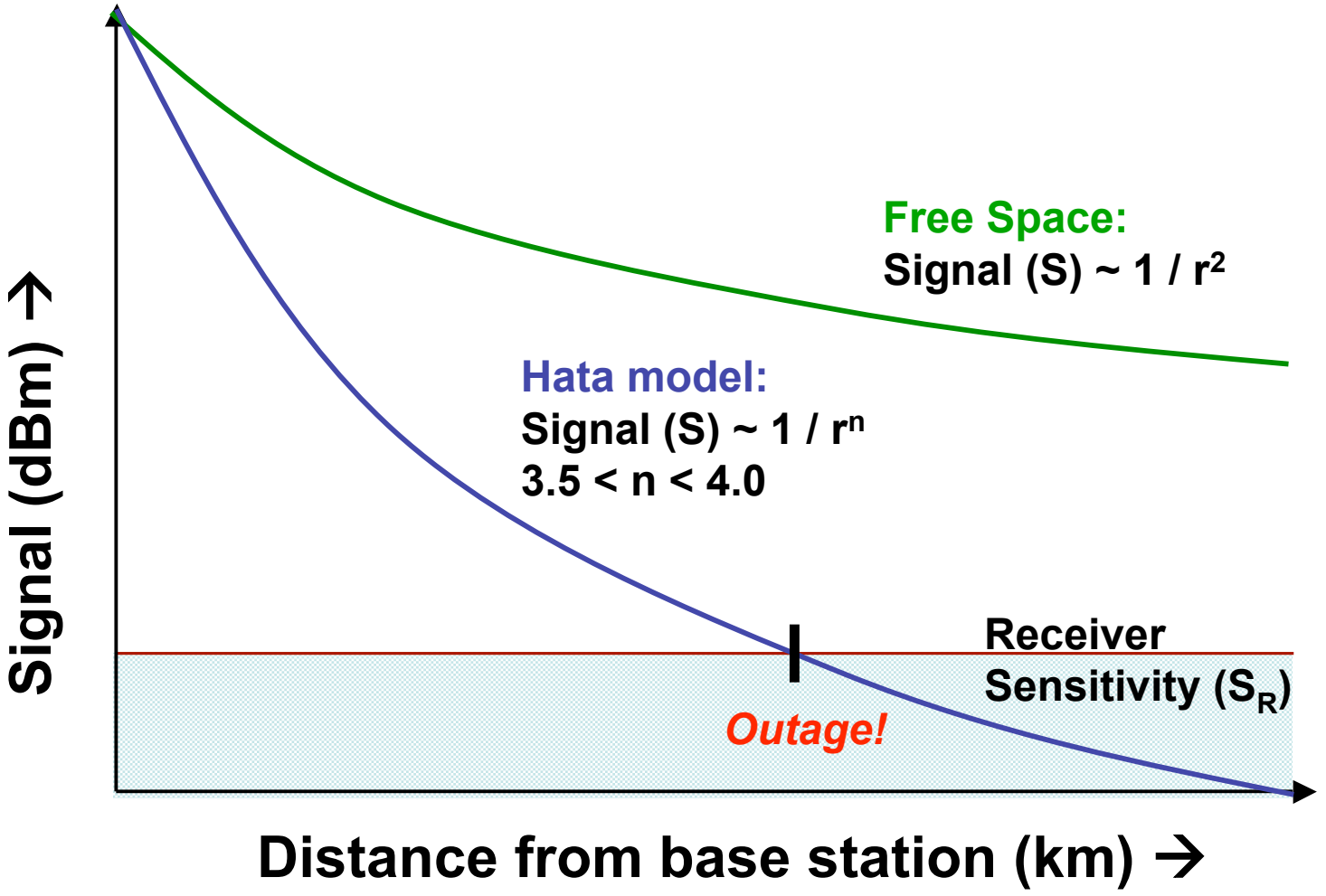
Signal **drops off** with inverse power law ~ $(1/d)^n$, $2<n<5$

Obstacles create **shadows, nulls, attenuation**

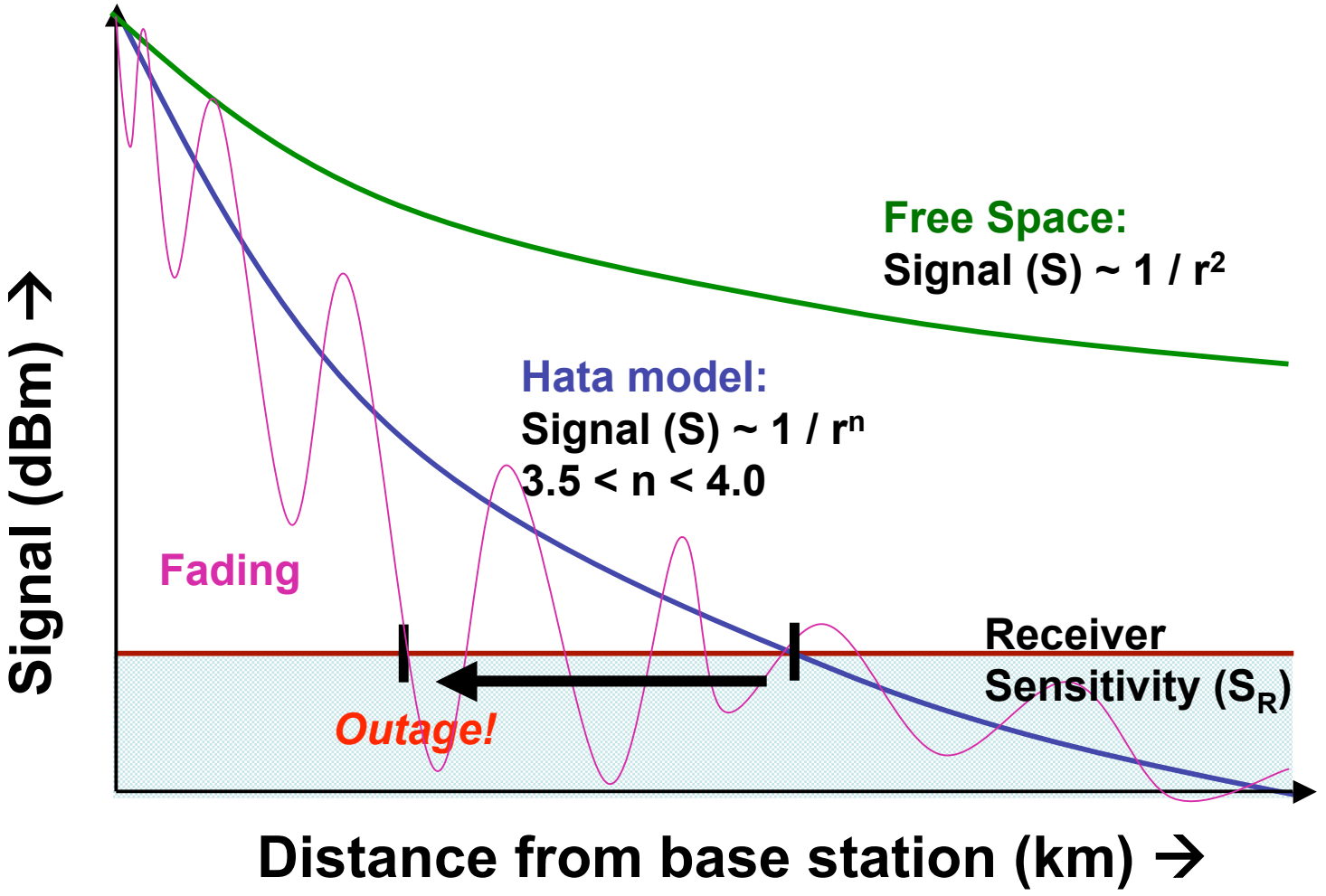
Reflections result in time-varying multipath **fading**

Propagation through the environment causes non-uniformity of coverage (SNR << 1)

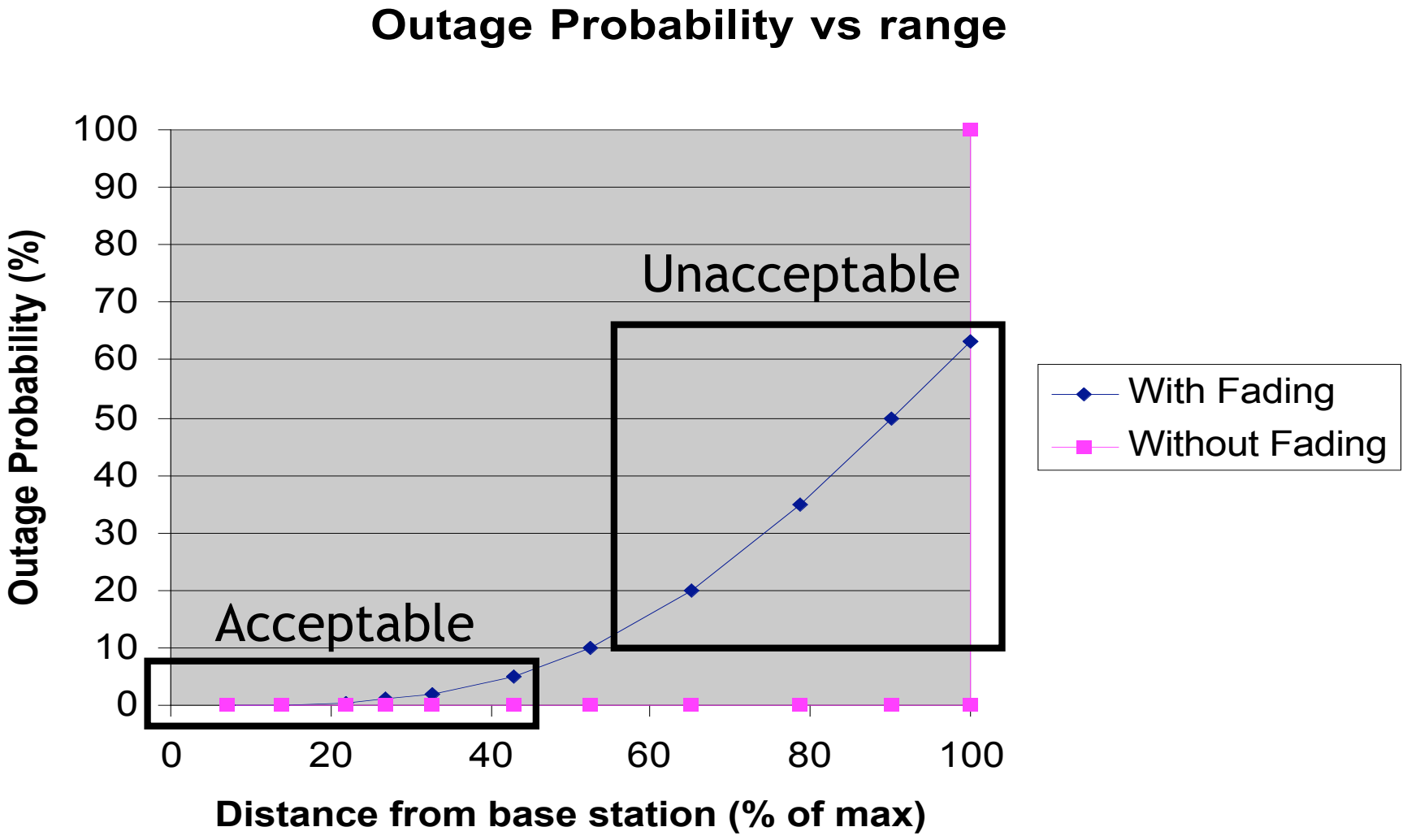
Capacity per user: RF Link Budget



Capacity per user: Fading Effects



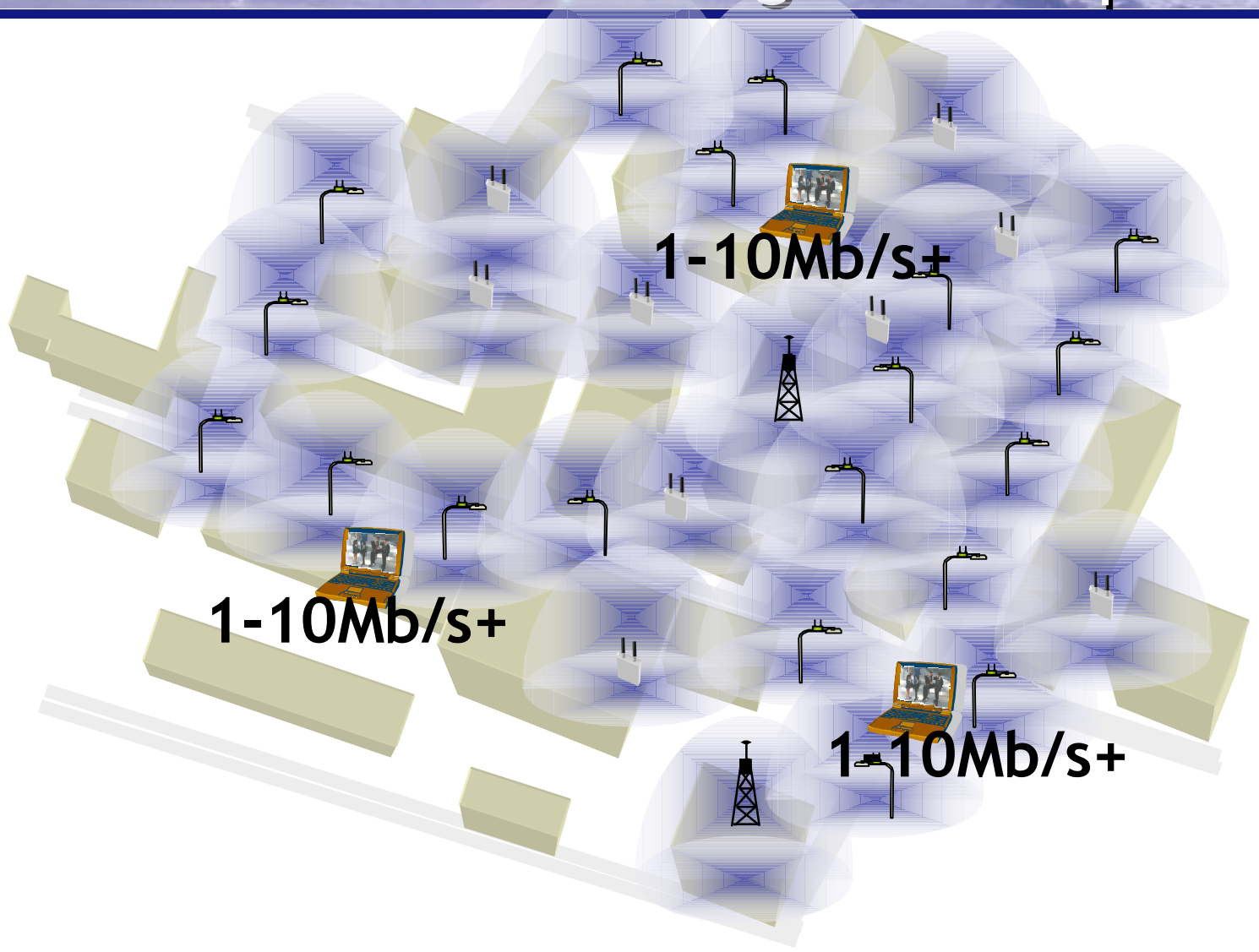
Capacity per user: Outage Probability



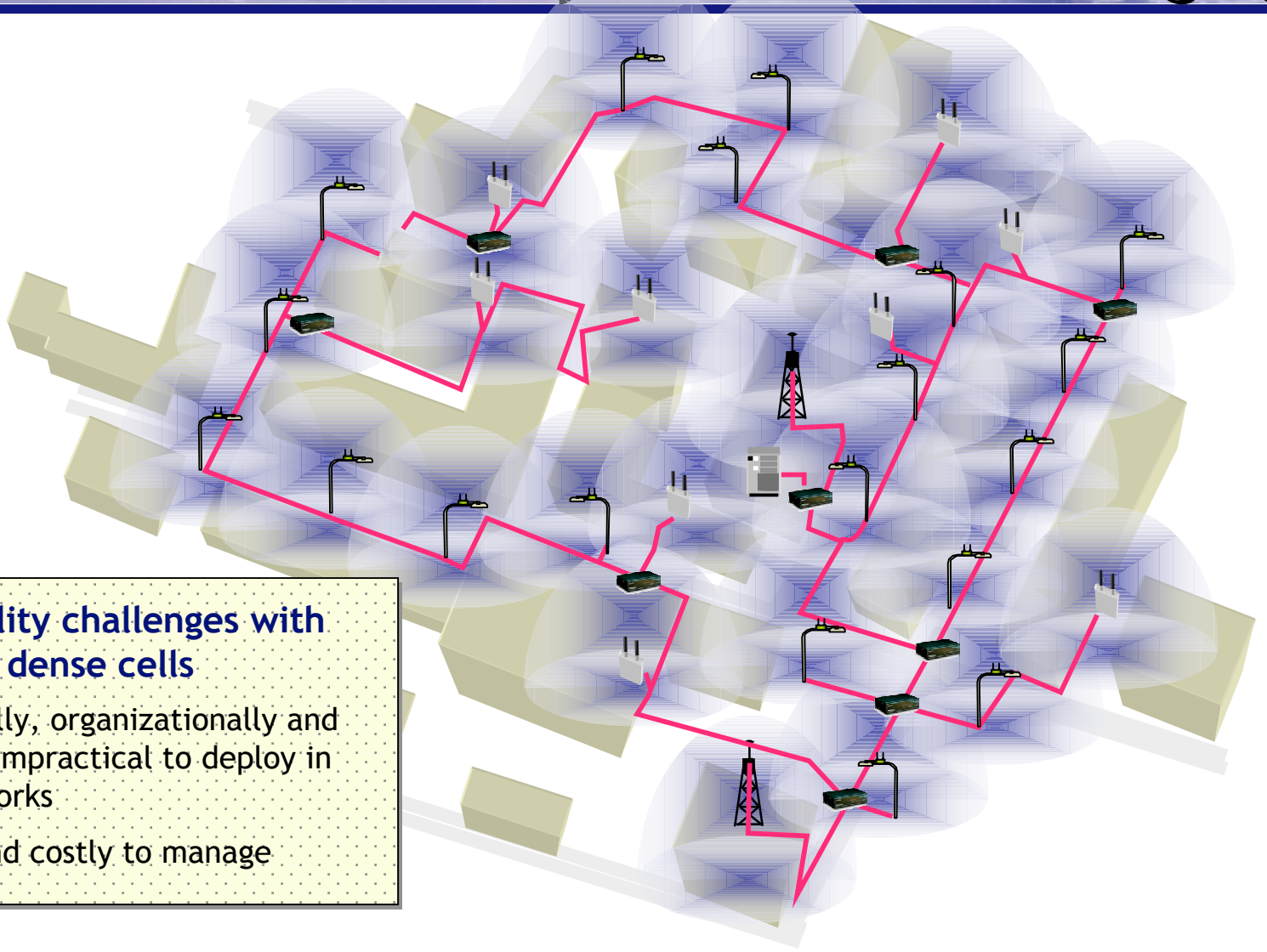
Capacity per user: Conclusions

- Uniform coverage requires signal above noise floor at receiver (SNR >> 1)
- Signal power is lost to environmental absorption and scattering, working against the aim of uniformity
- Large cells with high transmit power or focused beams/sectors require expensive hardware, but the resulting coverage isn't necessarily uniform
- *Cell density determines aggregate capacity*

Dense Cells: Uniform Coverage with Capacity



Dense Cells: Scalability Becomes Challenging



Scalability challenges with dense cells

- Economically, organizationally and physically impractical to deploy in large networks
- Difficult and costly to manage

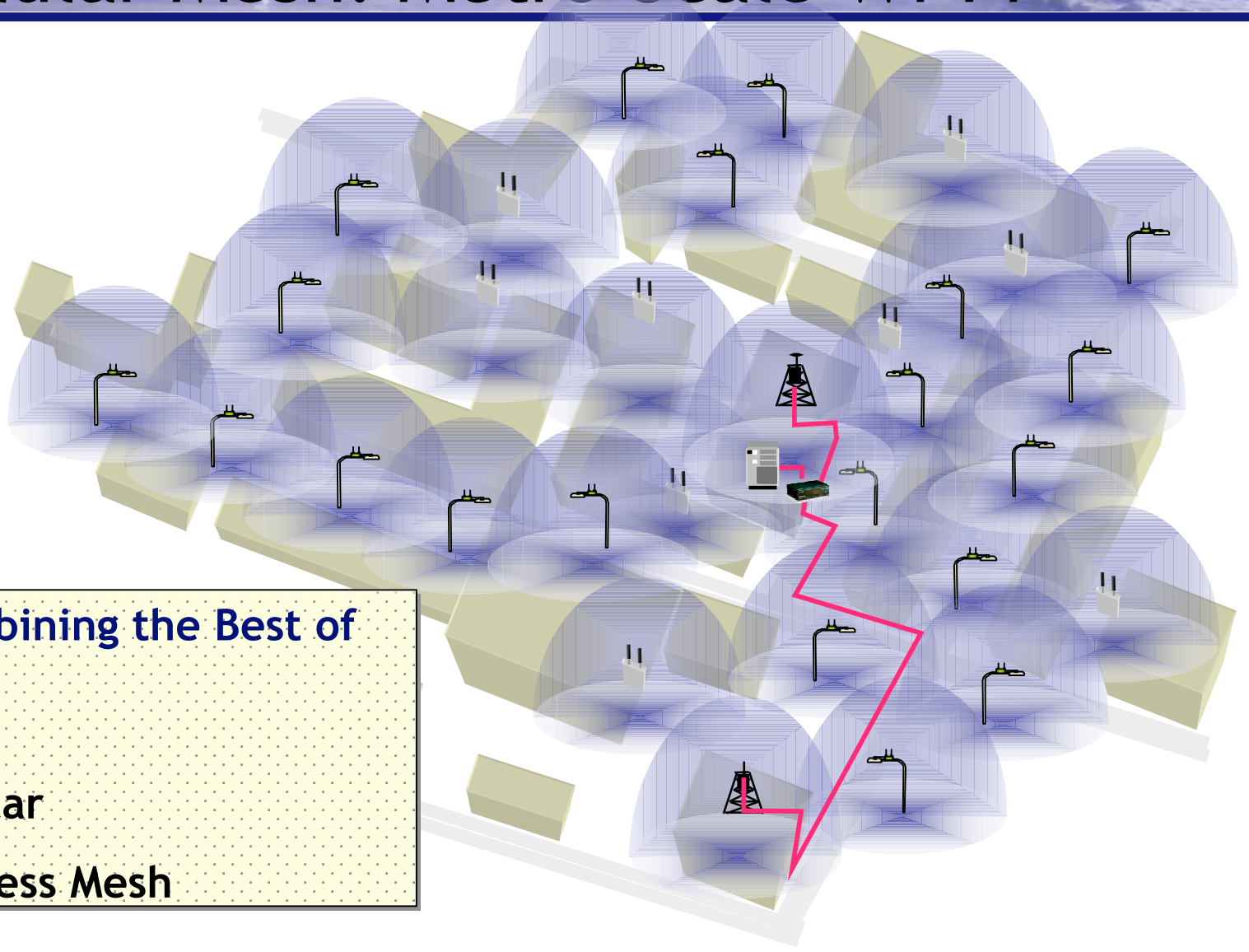
Wireless Network Architectures

- 1970s: Wireless Mesh (military)
  - Self-Organizing
  - Rapid deployment
  - Resilient to failures
- 1980s: Cellular Telephony (carriers)
  - Worldwide Adoption
  - Ubiquitous Coverage (licensed macro-cells)
- 1990s: Wi-Fi (PC industry)
  - Unlicensed multi-megabit speeds
  - Open standard (IEEE)
  - Laptops, PDAs, Cell phones (very near future)

Mesh Networking

- Active Research
  - MIT Roofnet
  - Carnegie Mellon Monarch
  - Naval Research Lab
- Growing industry presence
  - Startups: Tropos, MeshNetworks, BelAir, PacketHop, MeshDynamics, Firetide, Strix
  - Established companies: Intel, Nortel, Motorola
- IEEE 802.11s New Task Group
  - Framework for interoperability
  - Extensibility for all the different usage scenarios

Cellular Mesh: Metro-Scale Wi-Fi



Combining the Best of

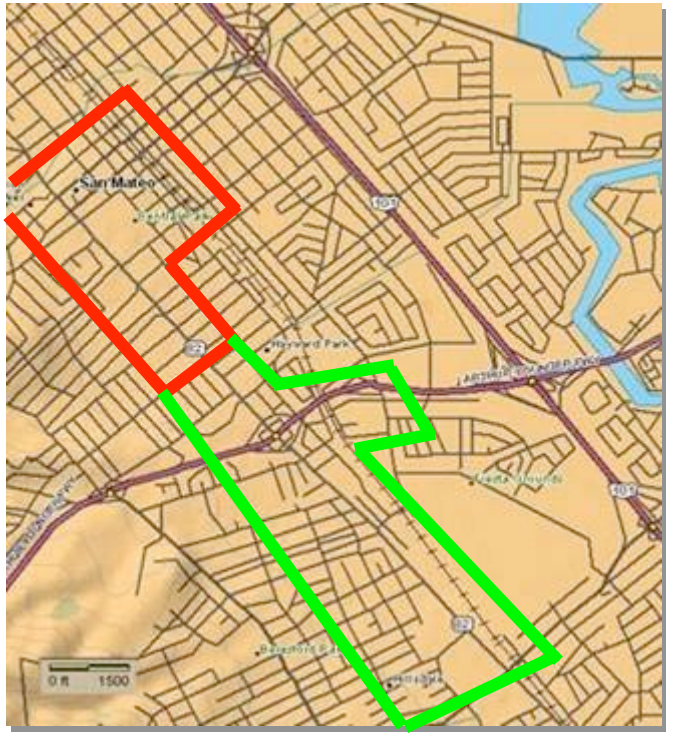
- Wi-Fi
- Cellular
- Wireless Mesh

Cellular Mesh: Metro-Scale Wi-Fi

- Eases deployment and scaling through a self-organizing IP network
- Allows wired backhaul to be added in line with subscriber growth by eliminating the need to wire every node
- Maximizes throughput, even in large networks
- Ensures reliability with an efficient self-healing architecture
- Offers accessibility and mobility to standard Wi-Fi clients

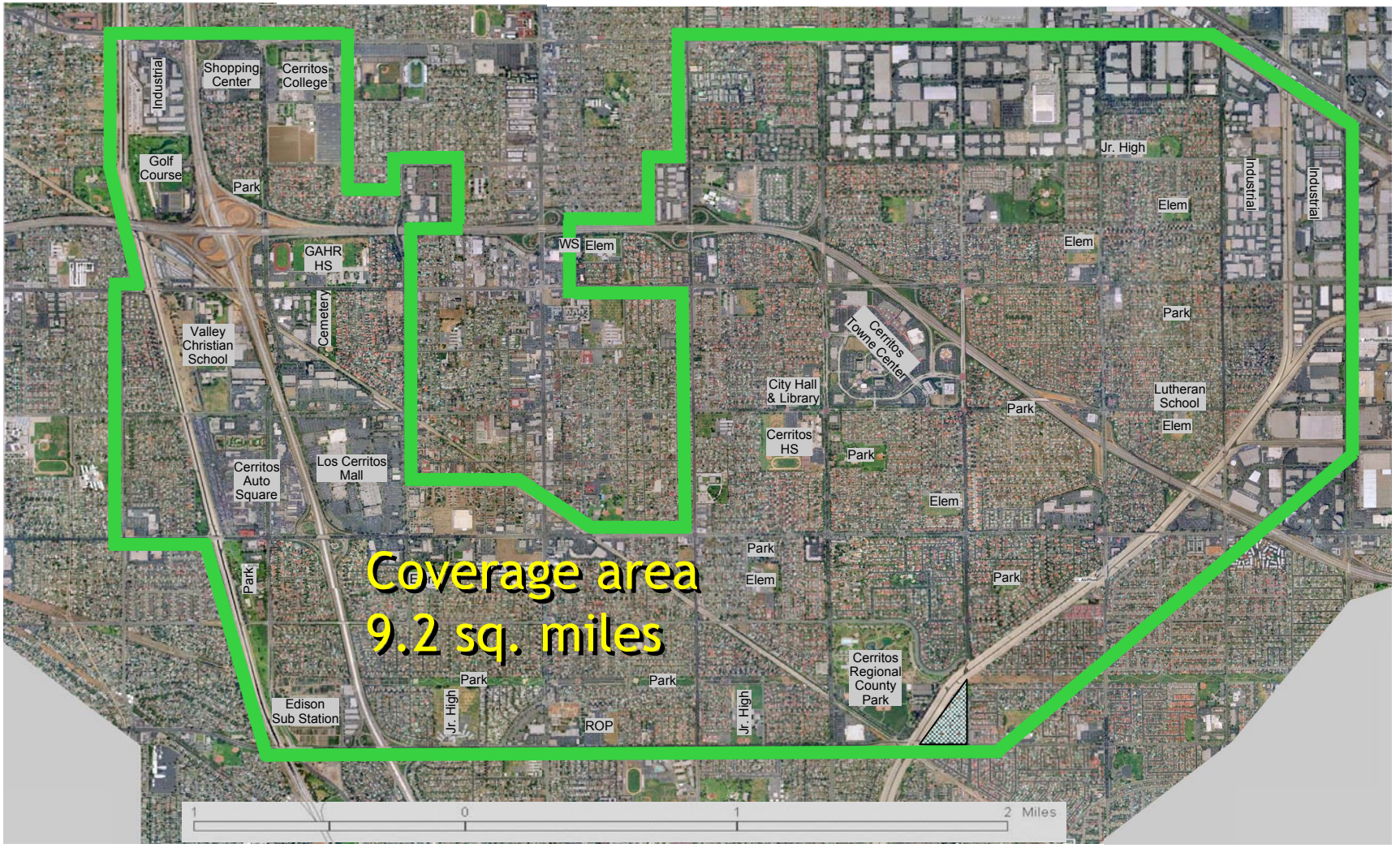
San Mateo PD Case Study

- Hot zone installed in downtown and along major thoroughfare
- Wi-Fi enabled laptops in patrol cars and Mobile Command Centers
- Access to LAWNET, a county-wide law enforcement Intranet
  - Amber Alert Information
  - Sex Offender Database
  - CA Gang Database
- DMV records, with high resolution photos
- In-field photo lineups
- Video monitoring in high-traffic areas



"Our Wi-Fi network now allows officers to take their office mobile. Because our officers now have broadband access to critical information, they can more quickly solve crimes in our community." ***Susan E. Manheimer, SMPD Chief of Police***

Cerritos Service Provider Case Study



Cerritos Service Provider Case Study

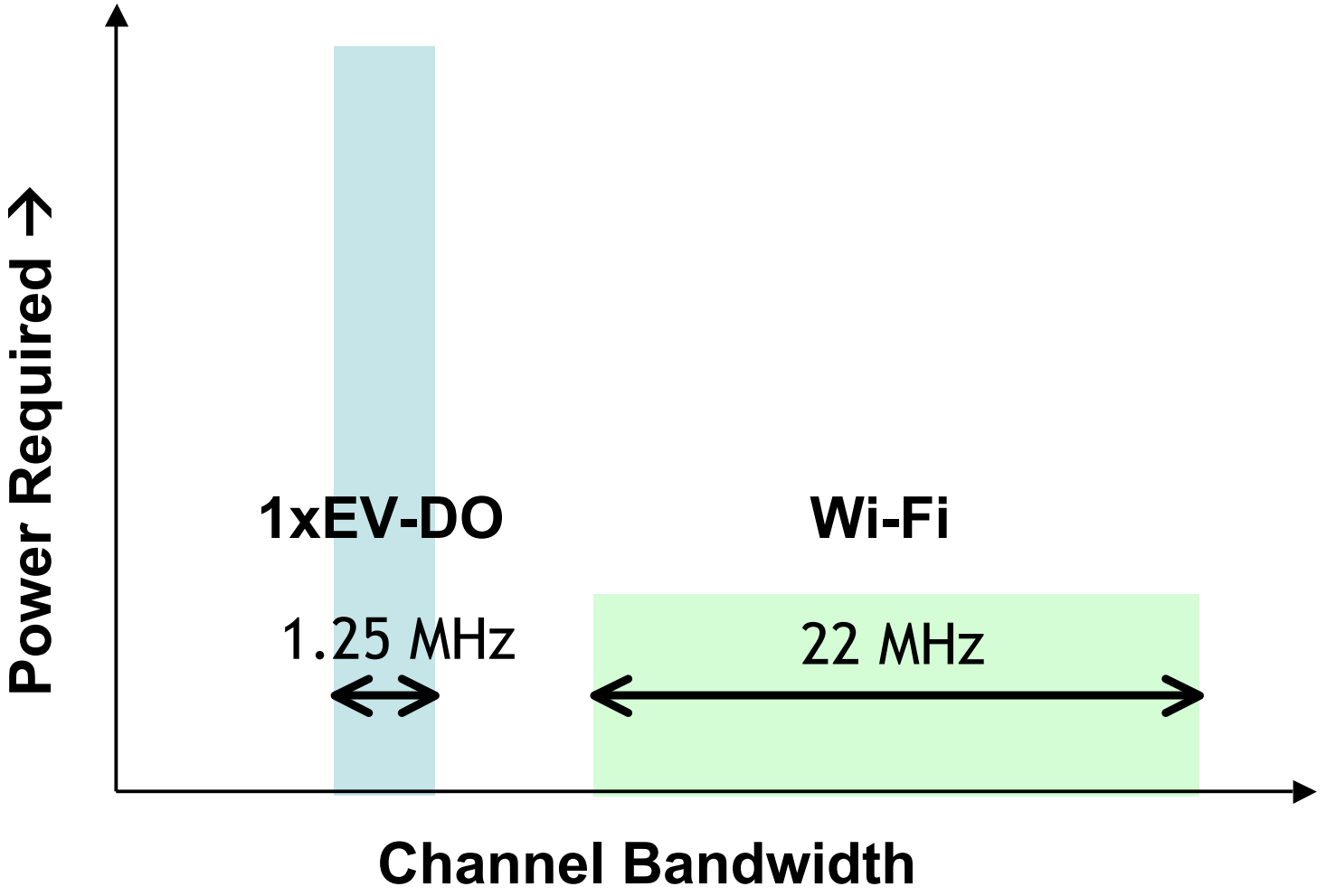
- AiirMesh is the service provider in Cerritos, CA
- Offering public metro-scale Wi-Fi access
  - Managed service to businesses and residences
- Service covers entire city
  - 9.2 sq. miles
  - 17,000 homes passed
- Serves multiple market segments
  - Public service and safety access
  - In cooperation with City Manager
- Network elements
  - Per user authentication and billing
  - Integrated 3rd party CPE device

aiirmesh
Wireless Community Broadband

3G

- So, how does metro-scale Wi-Fi compare to new "3rd Generation" offerings?
- 3G = 1xEV-DO (e.g., Verizon BroadbandAccess)

Broadband & Cell Density: 3G and Wi-Fi



Broadband & Cell Density: Shannon's Law

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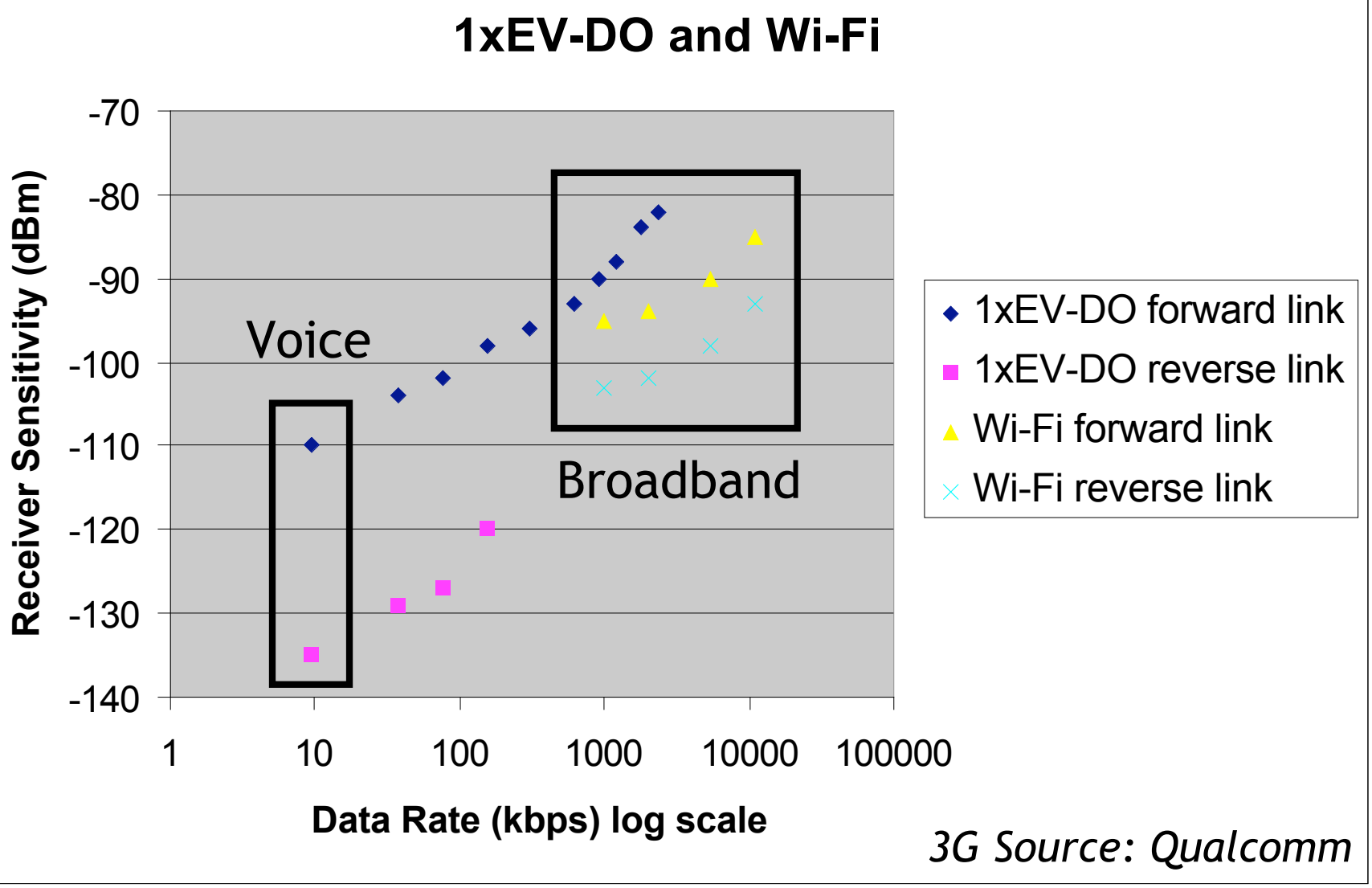
$$\text{Channel Capacity} = \boxed{\text{Bandwidth}} \times \log\left(1 + \frac{\text{Signal}}{\boxed{\text{Noise}}}\right)$$

Power

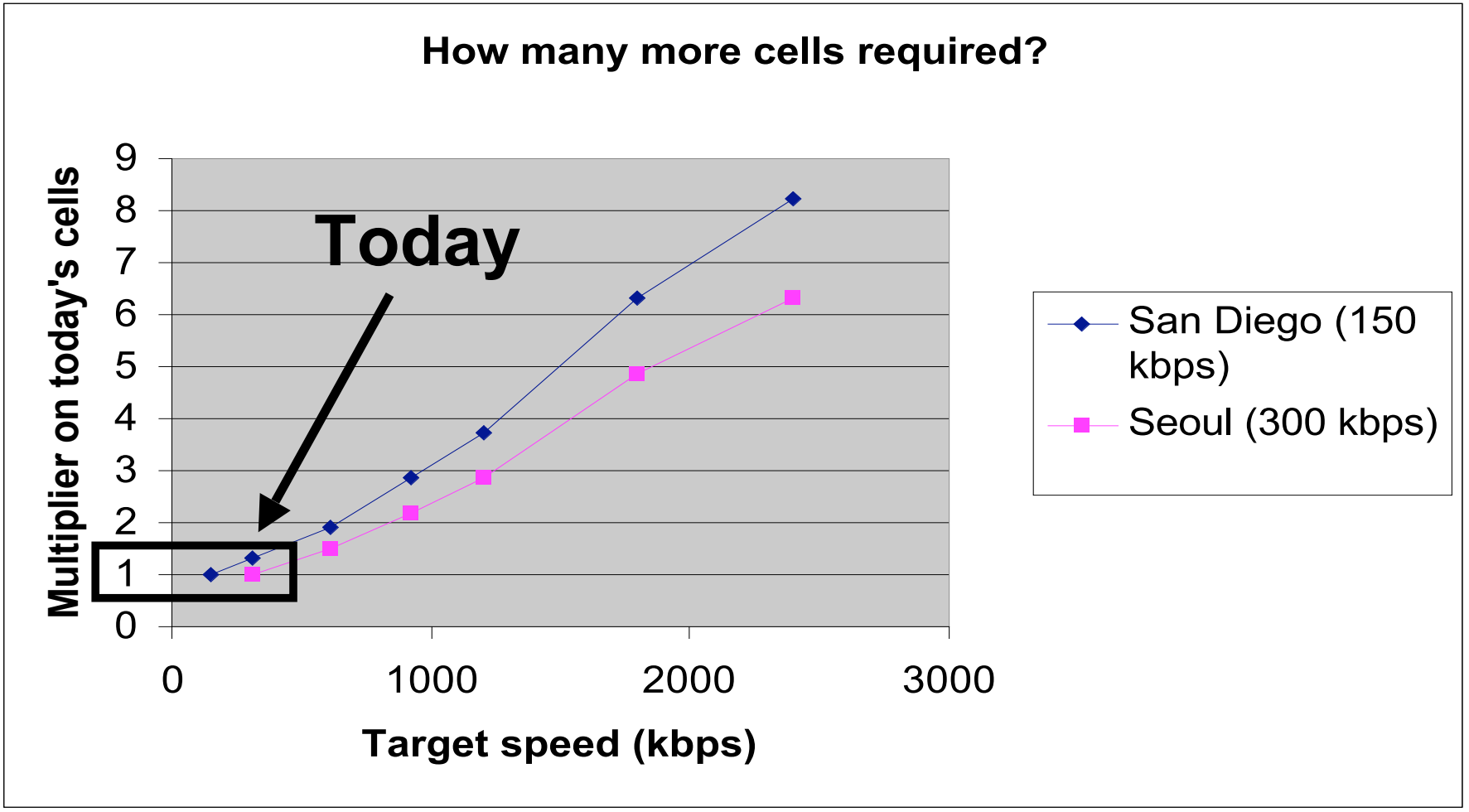
Broadband & Cell Density: Requires High SNR



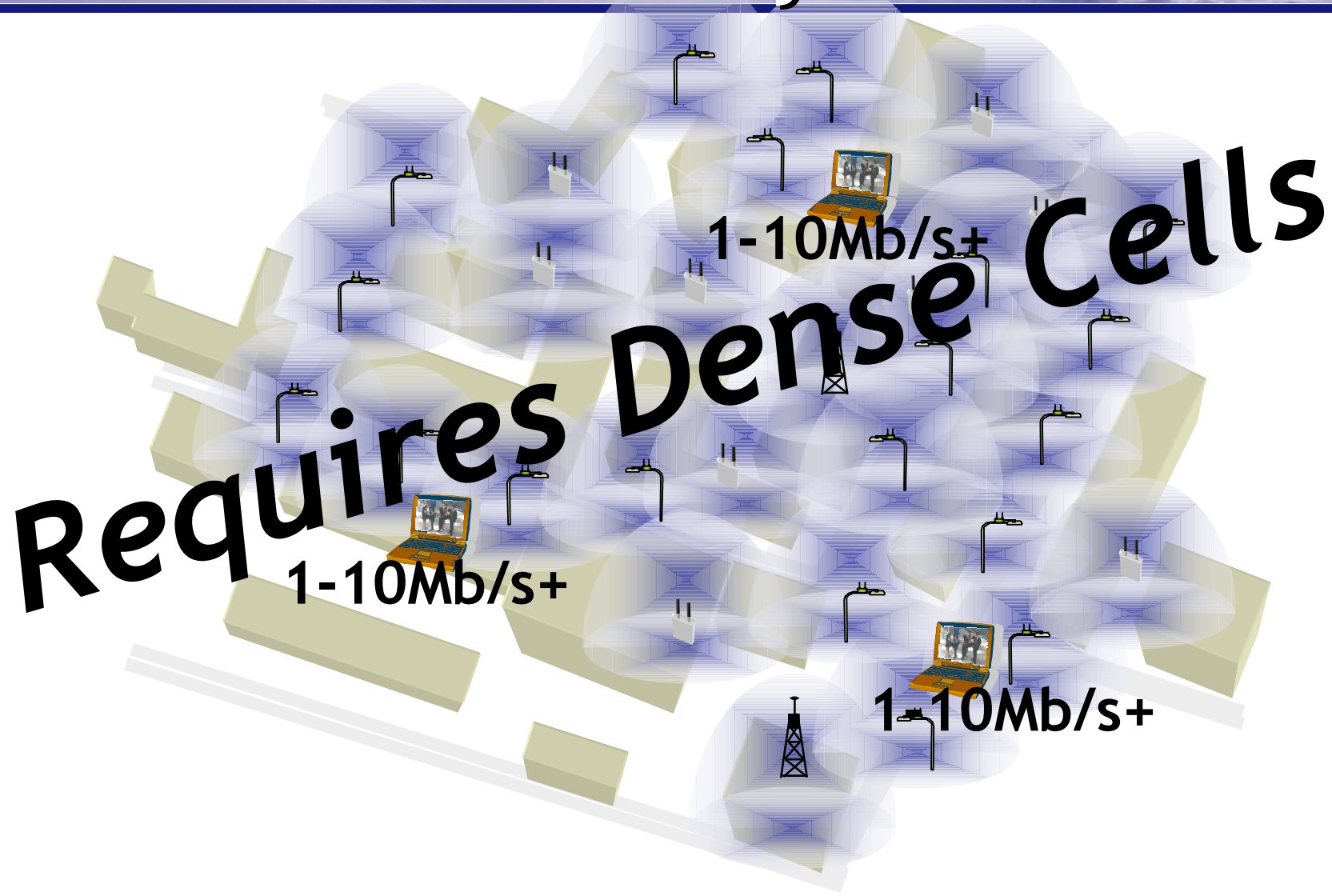
3G Source: Qualcomm

Broadband & Cell Density: 3G

Base Station Density ~ 1/(Link Budget)$^{2/n}$



Broadband & Cell Density: Uniform SNR

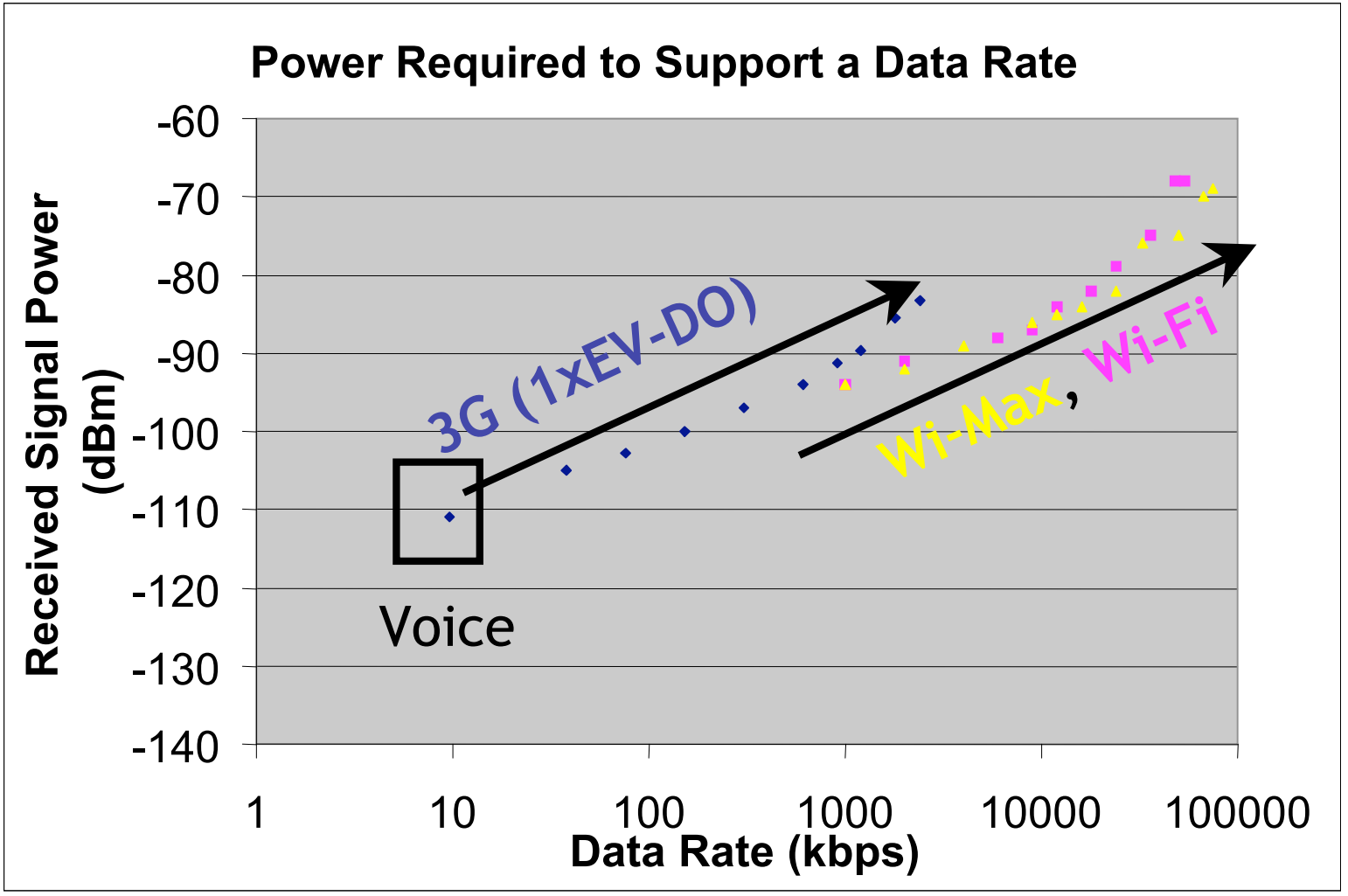


Applications eliminated by 1xEV-DO

- Video upload (download is questionable)
- PowerPoint, Rich Media upload
- Music Sharing
- Interactive Gaming

Cellular Wi-Fi makes them all possible.

WiMax and 3G Need Dense Cells



Price-Performance: Manhattan (34 sq. mi.)

	Cells	Performance
3G (1xEV-DO)	40	Down: 150-400 kbps Up: 10-50 kbps
Wi-Fi	600	500-2000 kbps *symmetric*

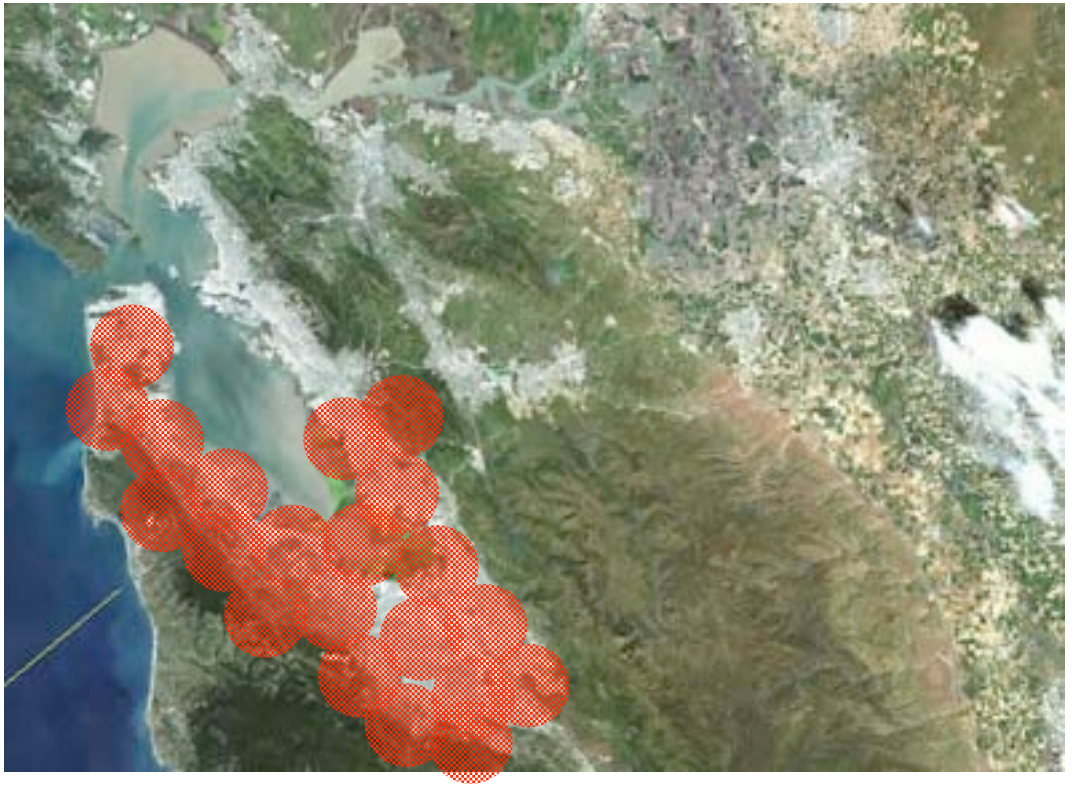
Wi-Fi Advantage

- 5x More Performance
- Less Costly

Findings

Compared to 3G… Cellular Wi-Fi is 5x faster, symmetric, and less expensive
3G, WiMax, and every other radio technology will also require dense cells
802.11 technology will be dramatically improving in the future (11g, 11n, 11e, etc)

Building the Broadband Atmosphere



The metro-scale cellular mesh system is the most reliable, cost effective, and easiest way to deploy broadband **Wi-Fi** over large geographic areas

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