4G Wireless Networks

Need for Improved Loss Tolerance

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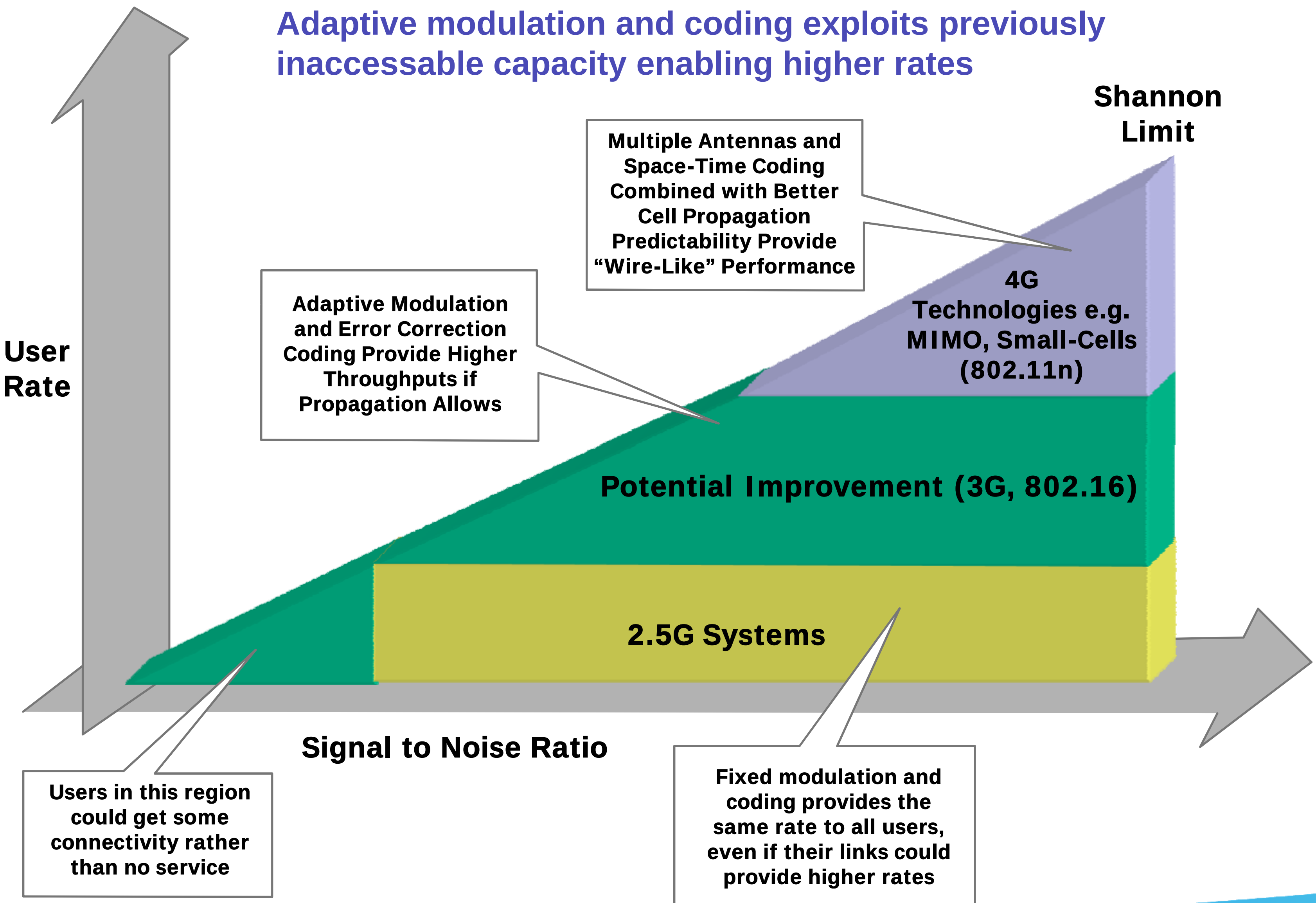
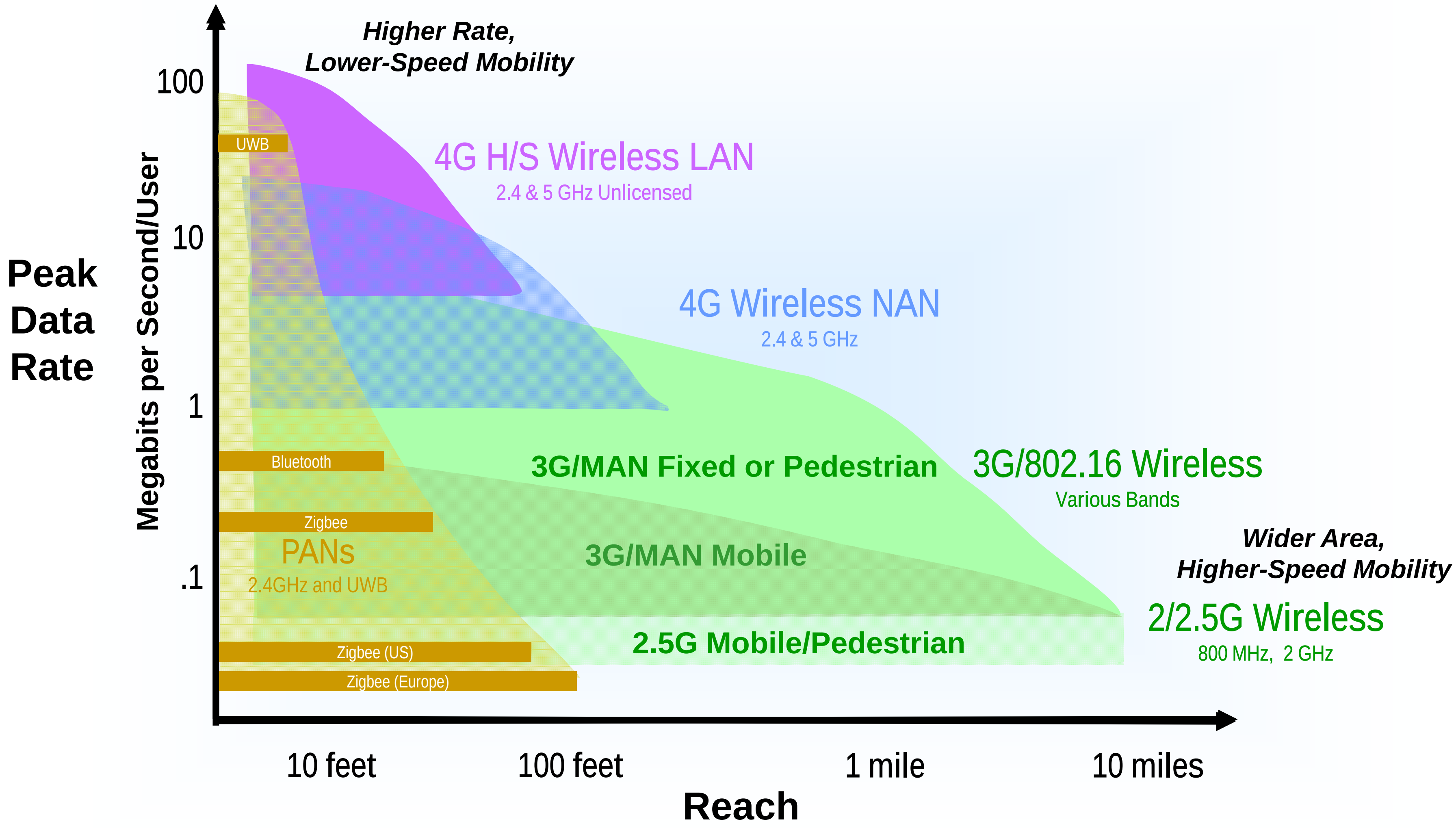
Adaptive Wireless: Goal is to Make Wireless As Good As Wired

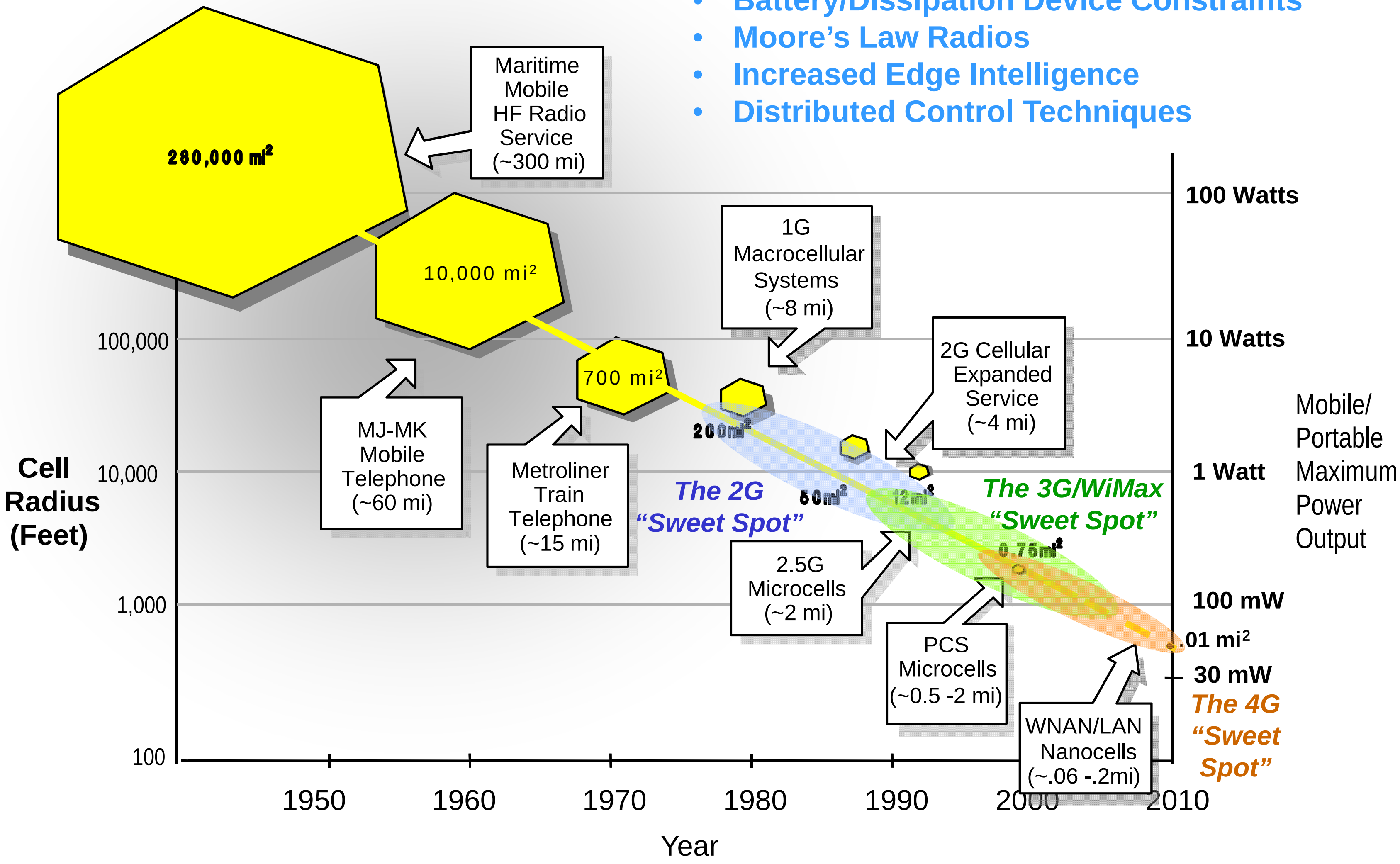


Reach-Data rate Tradeoff

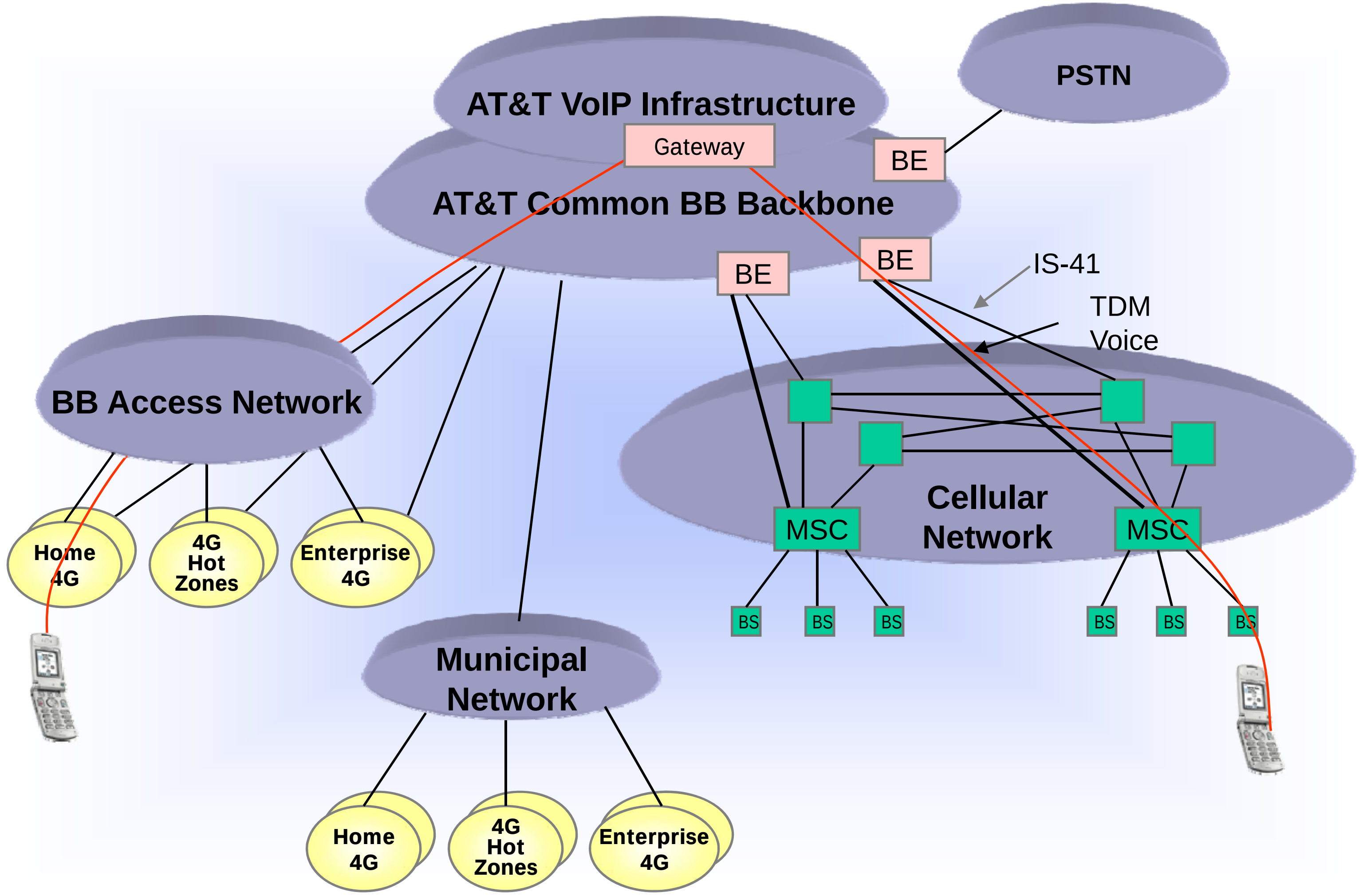


Cell Coverage Area Trends

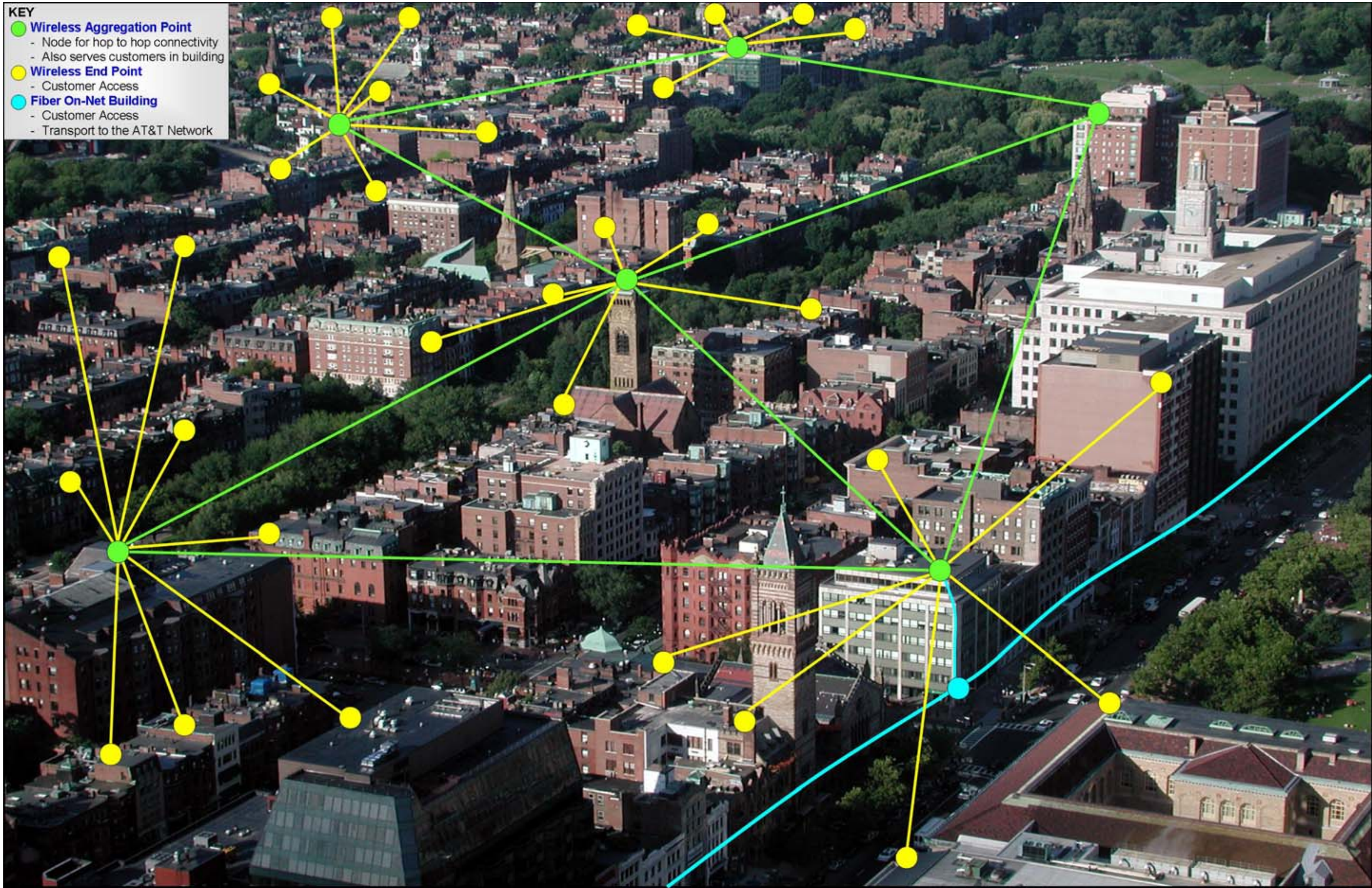
- Increased Bandwidth Demand/User
- Battery/Dissipation Device Constraints
- Moore's Law Radios
- Increased Edge Intelligence
- Distributed Control Techniques



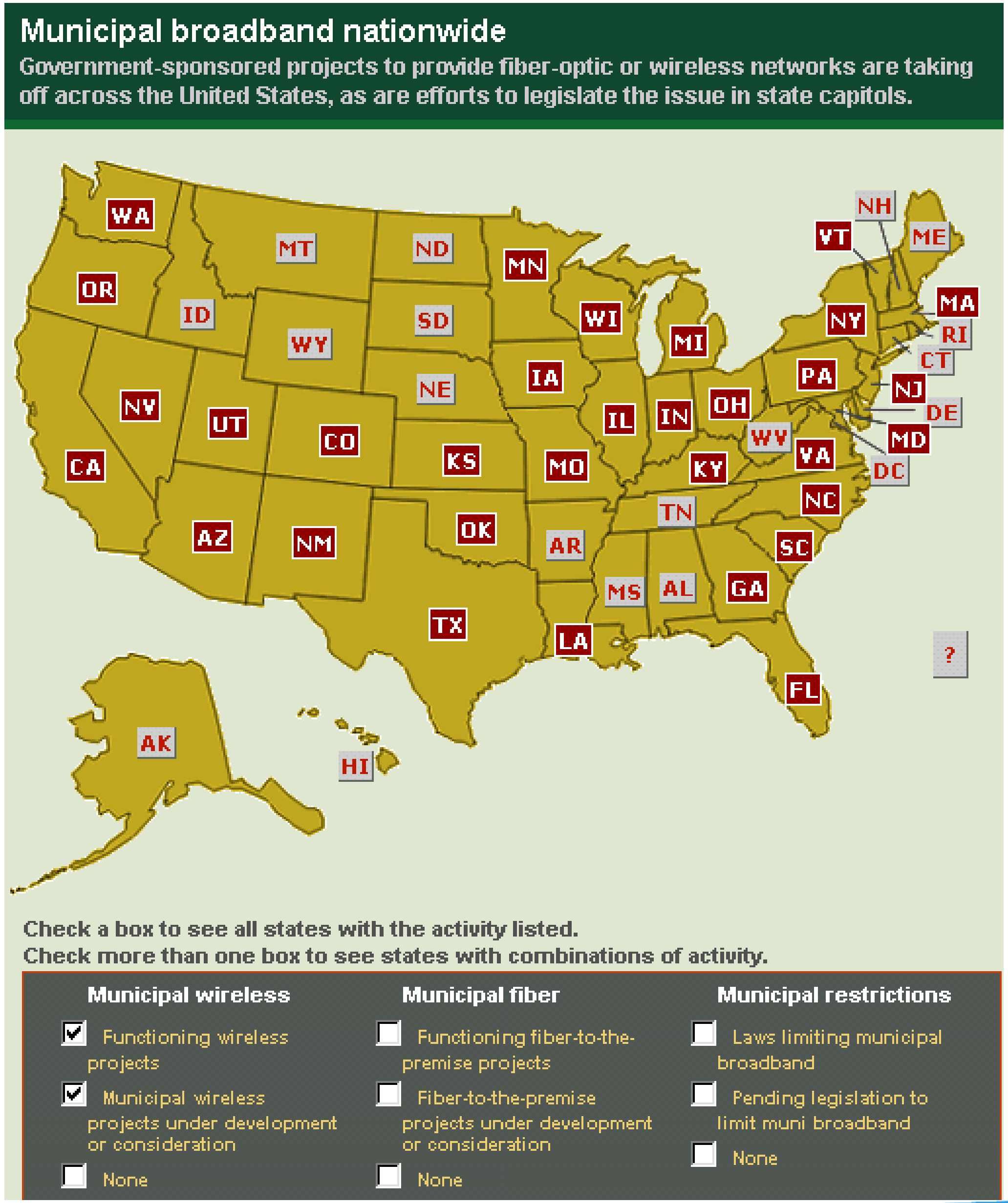
Architecting a 2G-3G-4G Wireless “Network Infrastructure”



How Might A Wireless Deployment Look?



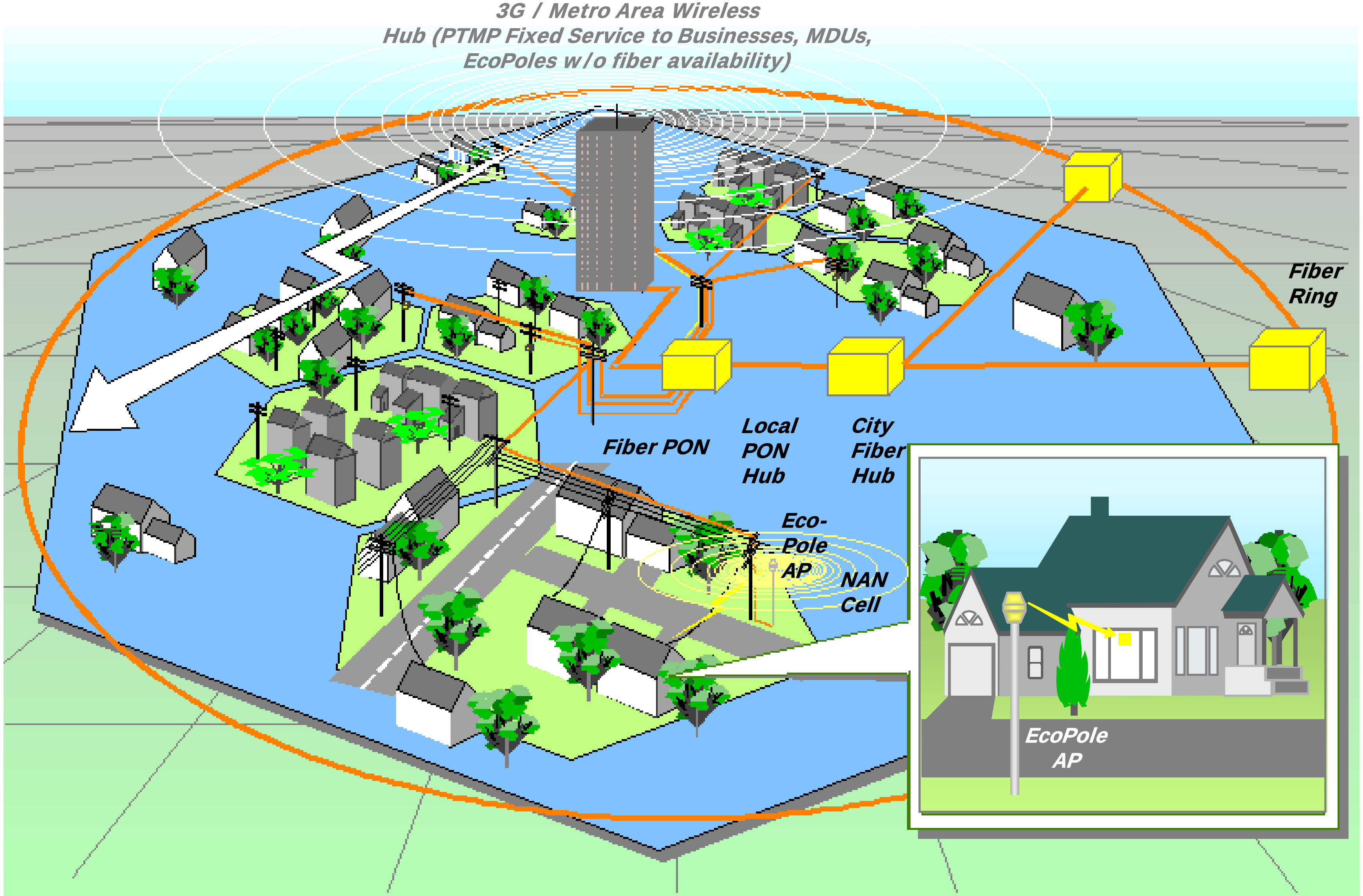
The Muni Network Concept Gets “Legs”



The number of municipalities operating, installing, or planning Wi-Fi networks is growing rapidly, driven by…

- User acceptance/use of Wi-Fi
- Large number of devices already equipped (instant customer base)
- Availability of low-cost networking systems (including mesh)
- Ability to transport Ethernet-like throughputs
- Desire to project “Cybercity” image
- “Digital Divide” amelioration
- Improvement in public service communications capabilities
- Leverage existing municipal infrastructure and fiber
- Revenue opportunities/new business models
- Ability to raise bond capital for infrastructure

Fiber, 4G, and Multi-Tier Wireless: A NanoNet



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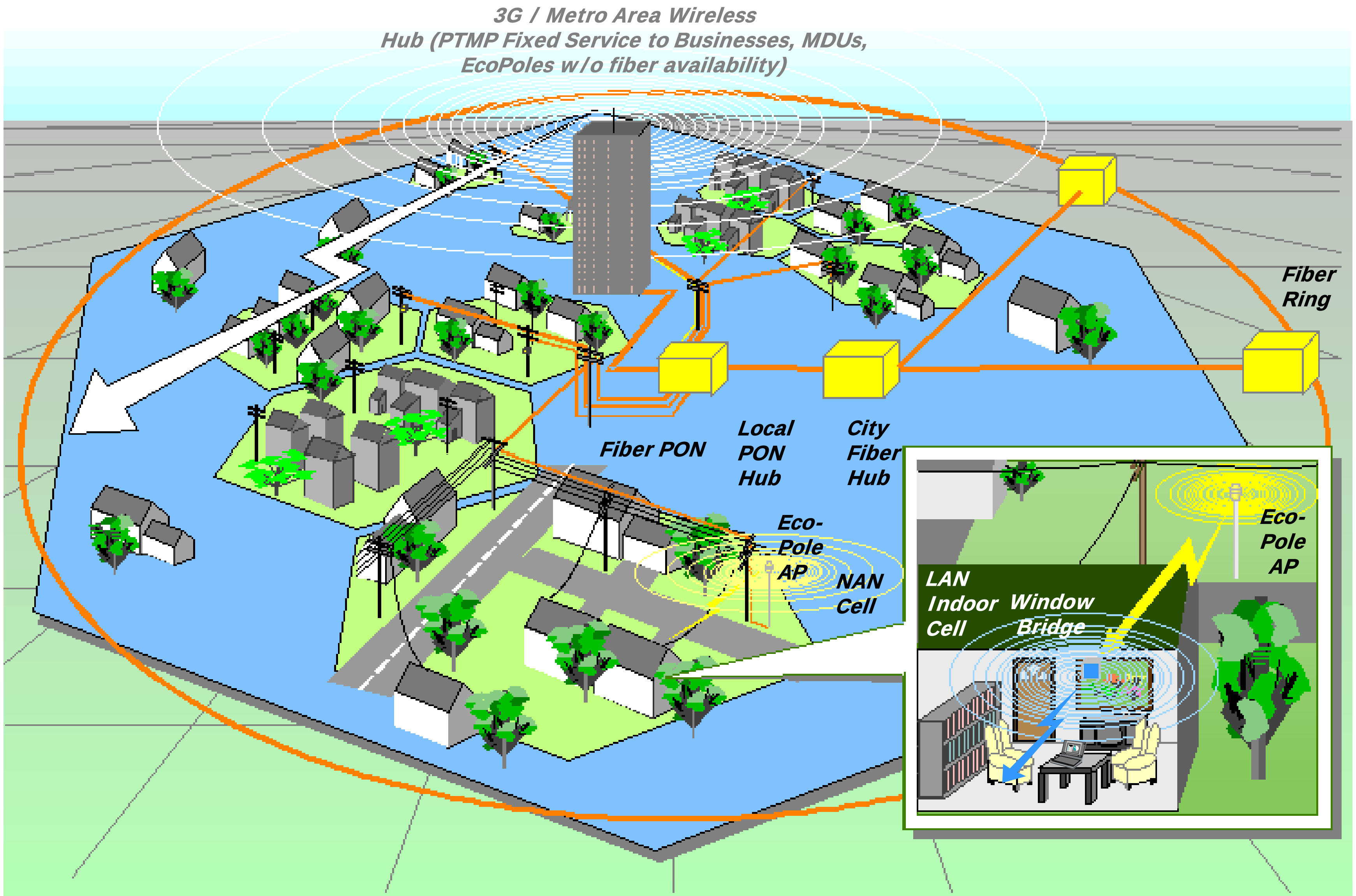
"NanoNet" Indoor Coverage Using "Window Bridging"



Solving Outdoor-to-Indoor Penetration: The Window Bridge

Motivation for our work on LT-TCP

- Dense wireless deployments in urban areas/ high rises will cause disruptions/ burst errors due to interference
- Protocols need to be loss tolerant and provide reliability
  - Especially as we move to multi-hop wireless environments
- Divide the burden of reliability between link and transport layers
- Keep Residual Loss Rate low; Delay small; Link and Transport Layer Goodput high

TCP-SACK Performance under Lossy Conditions

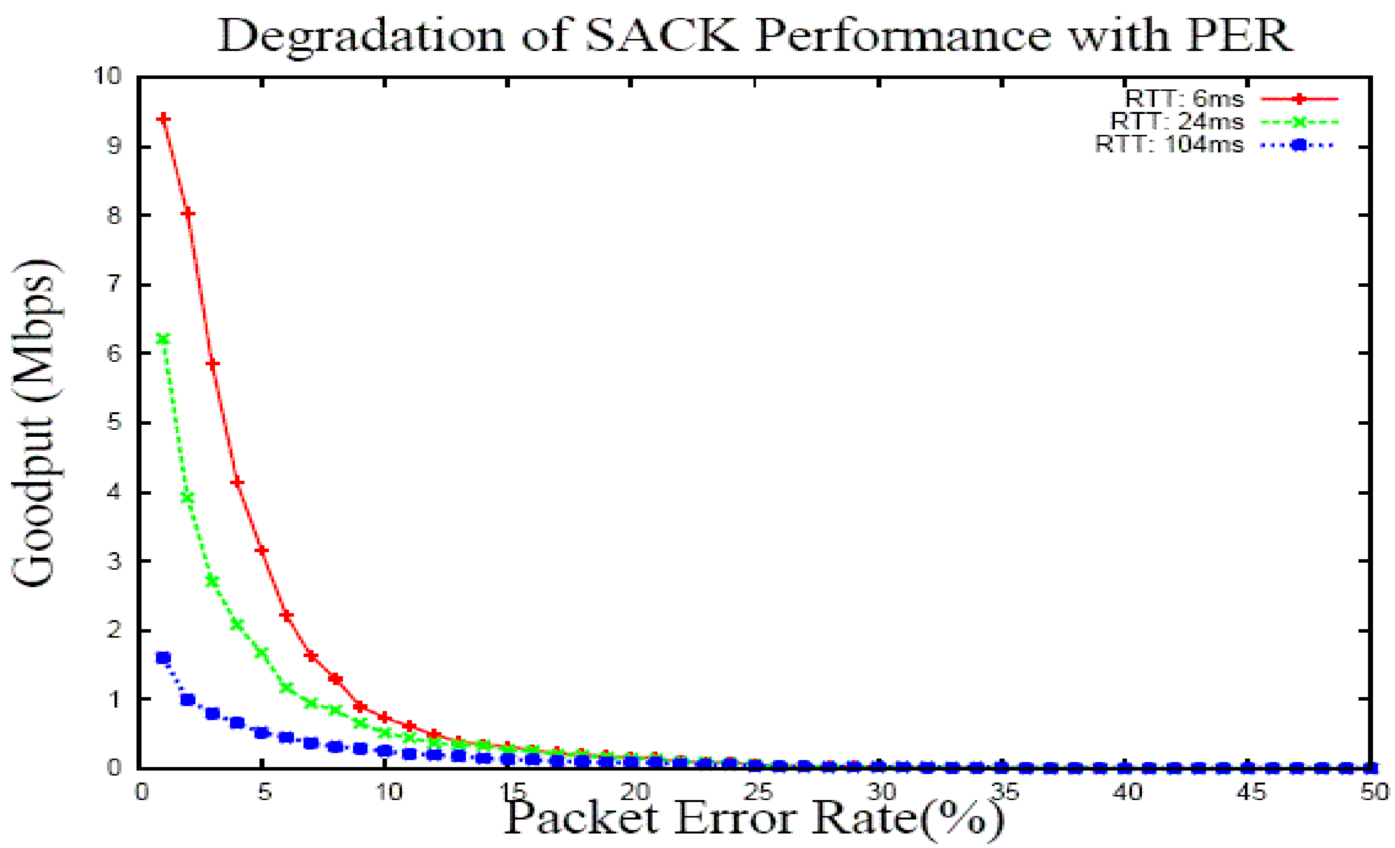


Fig. 1. TCP-SACK Degradation with Increased Erasure Rate and RTT (Uniform Loss Probabilities, 10 Mb/s Capacity, 1 flow)

- Sharp drop-off in performance with PER (degrades beyond an error rate of 5% PER)
- Performance is poorer as combination of PER and RTT grows

Goals for our Enhancements to TCP

- **Dynamic Range:**
  - Can we extend the dynamic range of TCP into high loss regimes?
  - Can TCP perform close to the theoretical capacity achievable under high loss rates?
- **Congestion Response:**
  - How should TCP respond to notifications due to congestion..
  - … but ***not*** respond to packet erasures that do not signal congestion?
- **Mix of Reliability Mechanisms:**
  - What mechanisms should be used to extend the operating point of TCP into loss rates from 0% - 50 % packet loss rate?
  - How can Forward Error Correction (FEC) help?
  - How should the FEC be split between sending it ***proactively*** (insuring the data in anticipation of loss) and ***reactively*** (sending FEC in response to a loss)?
- **Timeout Avoidance:**
  - Timeouts: Useful as a fall-back mechanism but wasteful otherwise especially under high loss rates.
  - How can we add mechanisms to minimize timeouts?
- **Our Enhancements to TCP: Loss Tolerant-TCP (LT-TCP)**

LT-TCP Performance

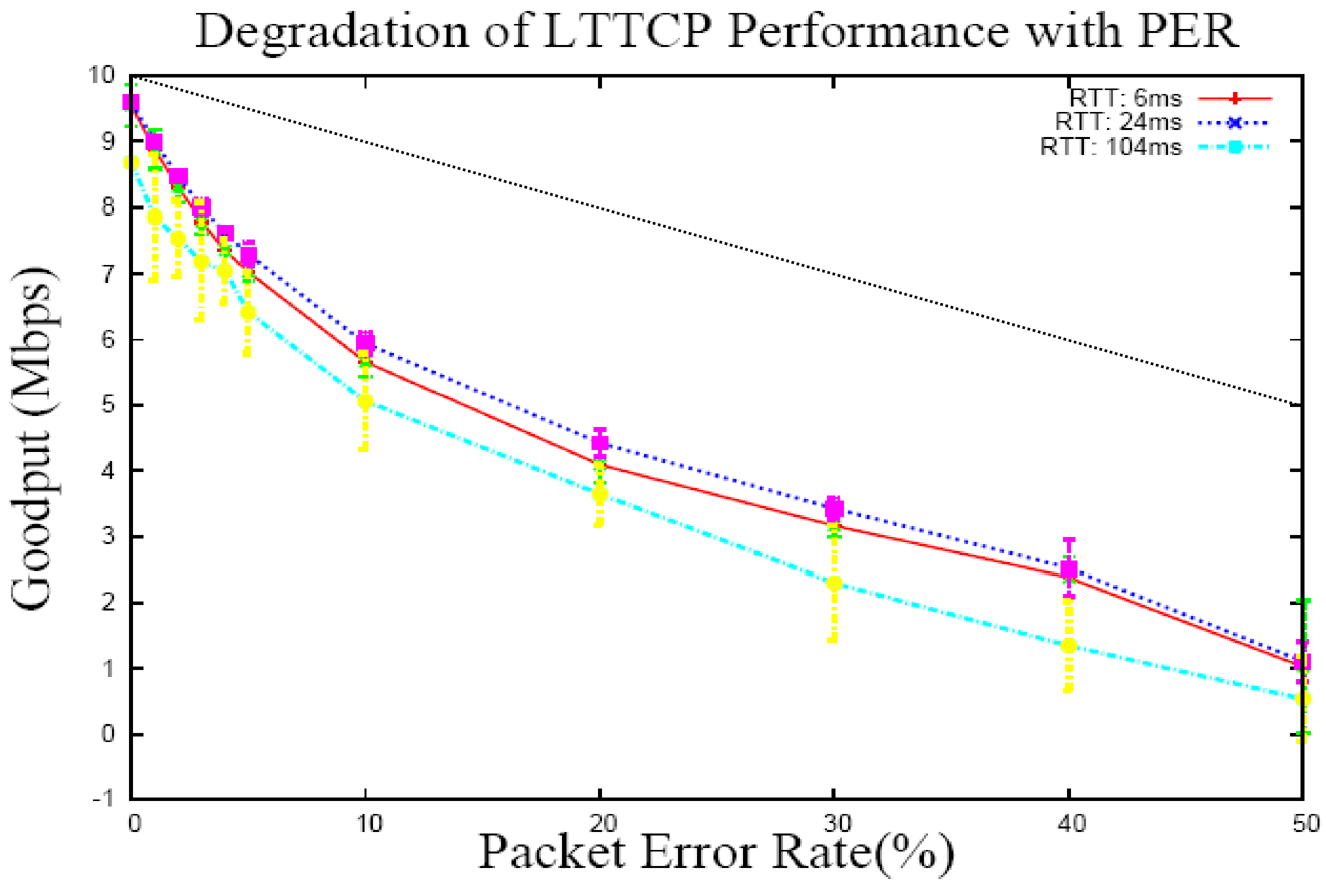


Fig. 4. LT-TCP performance with Increased Erasure Rate and RTT (Uniform Loss Probabilities, 10 Mb/s Capacity, 1 flow)

- Performance of LT-TCP is much better compared to that of TCP-SACK
- LT-TCP degrades gracefully (nearly linear degradation with loss rate)

Transport layer performance with loss tolerance across layers

- Combining Loss Tolerance at the Transport layer with Link layer enhancements allows us to strike a balance in providing the appropriate loss tolerance over a wide range of losses
- Limiting ARQ at link layer to manage latency
- Manageable link level residual loss rate
- Reasonable Goodput even under extreme conditions