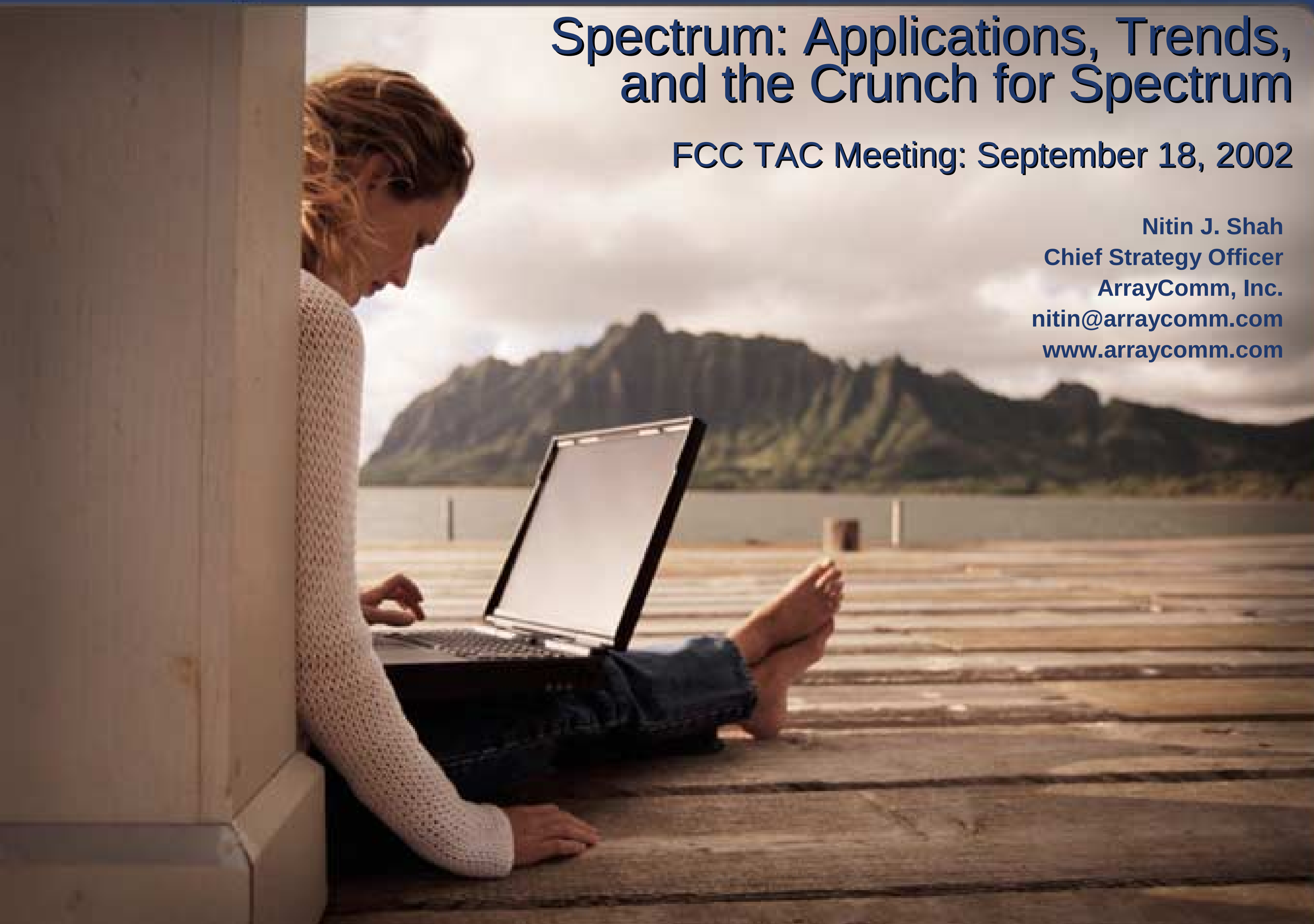
ArrayComm



Spectrum: Applications, Trends, and the Crunch for Spectrum

FCC TAC Meeting: September 18, 2002

Nitin J. Shah
Chief Strategy Officer
ArrayComm, Inc.
nitin@arraycomm.com
www.arraycomm.com

Outline

- Wireless access systems
- Applications and market segments
- Adaptive antennas
- Economics of wireless networks
- Spectral efficiency
- Recommendations

Wireless Access Systems

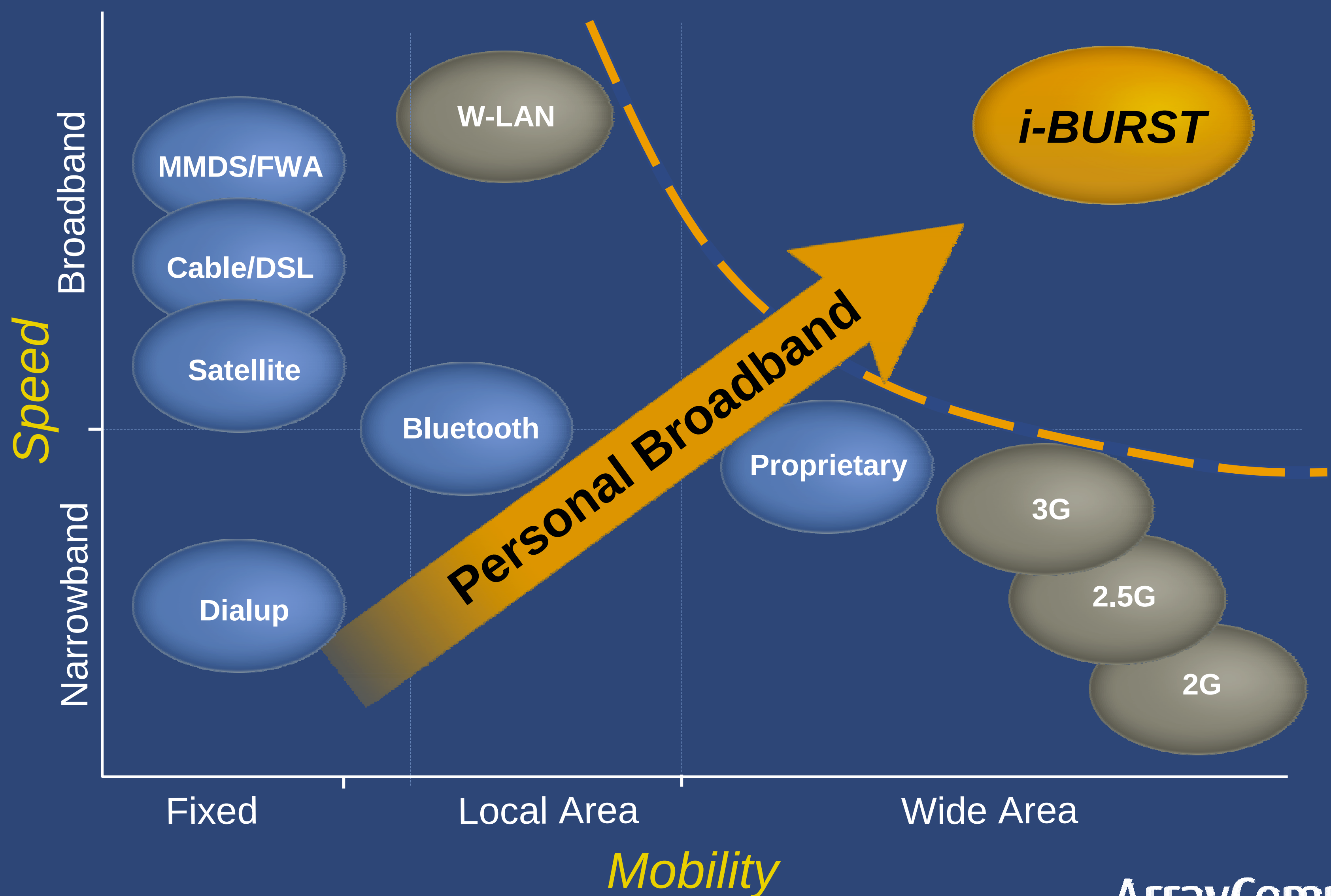
- **Multiple Access Systems**
  - TDMA, CDMA, OFDM (decreasing order of maturity)
- **Modulation techniques**
  - BPSK, QPSK, QAM (increasing requirements on linearity, power and cost)
- **Error correction coding**
  - Large family of error correction techniques, based on target performance requirements (voice, data, retransmission etc)
- **Performance**
  - Based on combinations of the above technologies
  - Most robust schemes use appropriate combination + adaptive modulation and link layer adaptation to achieve maximum and consistent multi-user performance
- **System capacity and end user device complexity drive the network economics**

Applications and Segments

- **LAN (> 10 Mb/s) (e.g. W-LAN, 802.11)**
  - High bandwidth, short range (cordless-like), unlicensed spectrum
- **WAN for voice (~ 8 kb/s) (e.g. GSM, CDMA; 2G)**
  - Low bandwidth, low latency, wide area, licensed spectrum
- **WAN for wireless data (~ 50 kb/s) (e.g. 2.5 and 3G)**
  - Moderate (and variable) bandwidth, wide mix of proposed services, wide area, licensed spectrum
- **WAN for Personal Broadband Services (> 1Mb/s)**
  - High bandwidth, wide mix of services, wide area, licensed spectrum

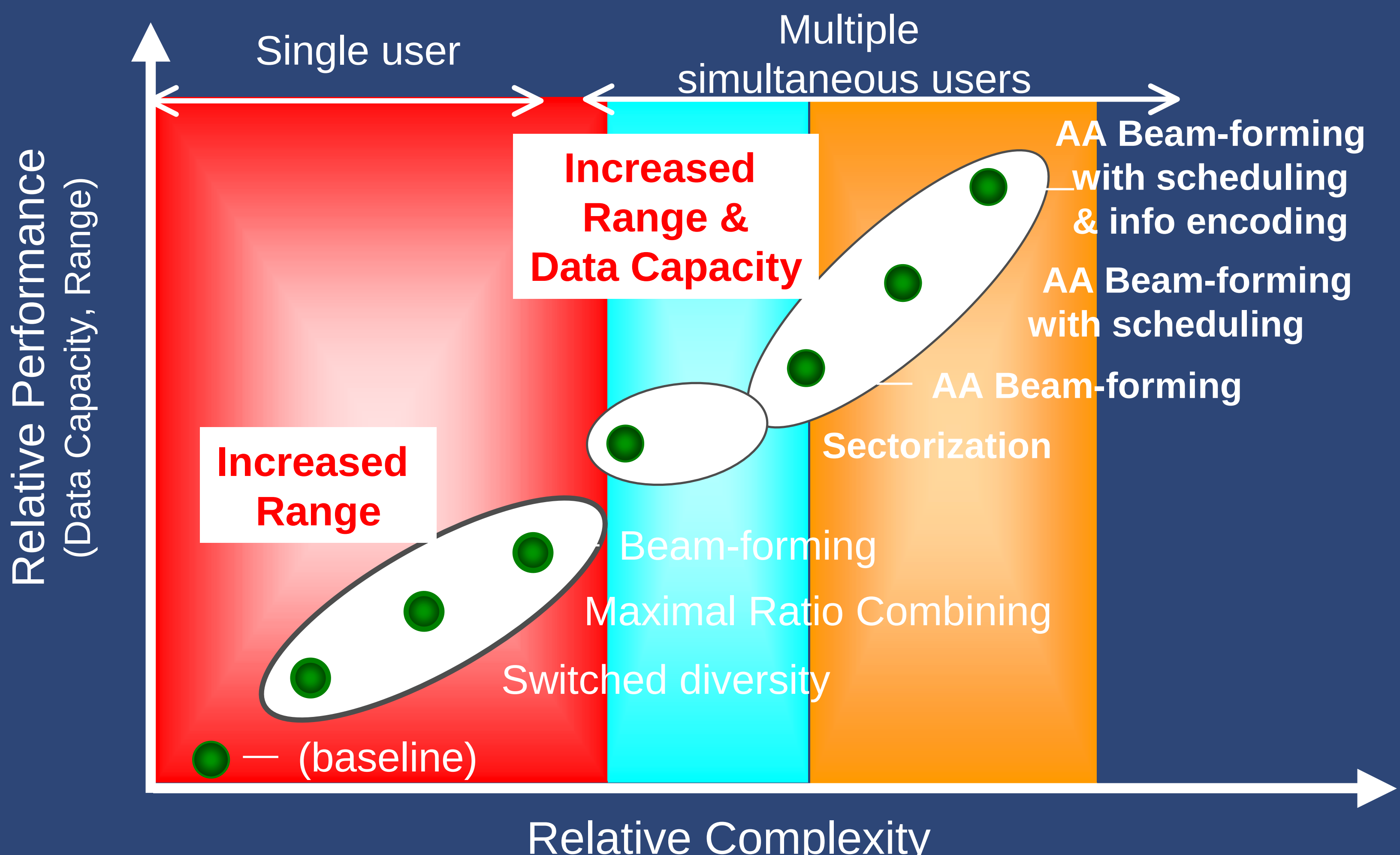
- *Need dramatically new physical and network layer technology to provide cost-effective broadband services*

Access Landscape



ArrayComm

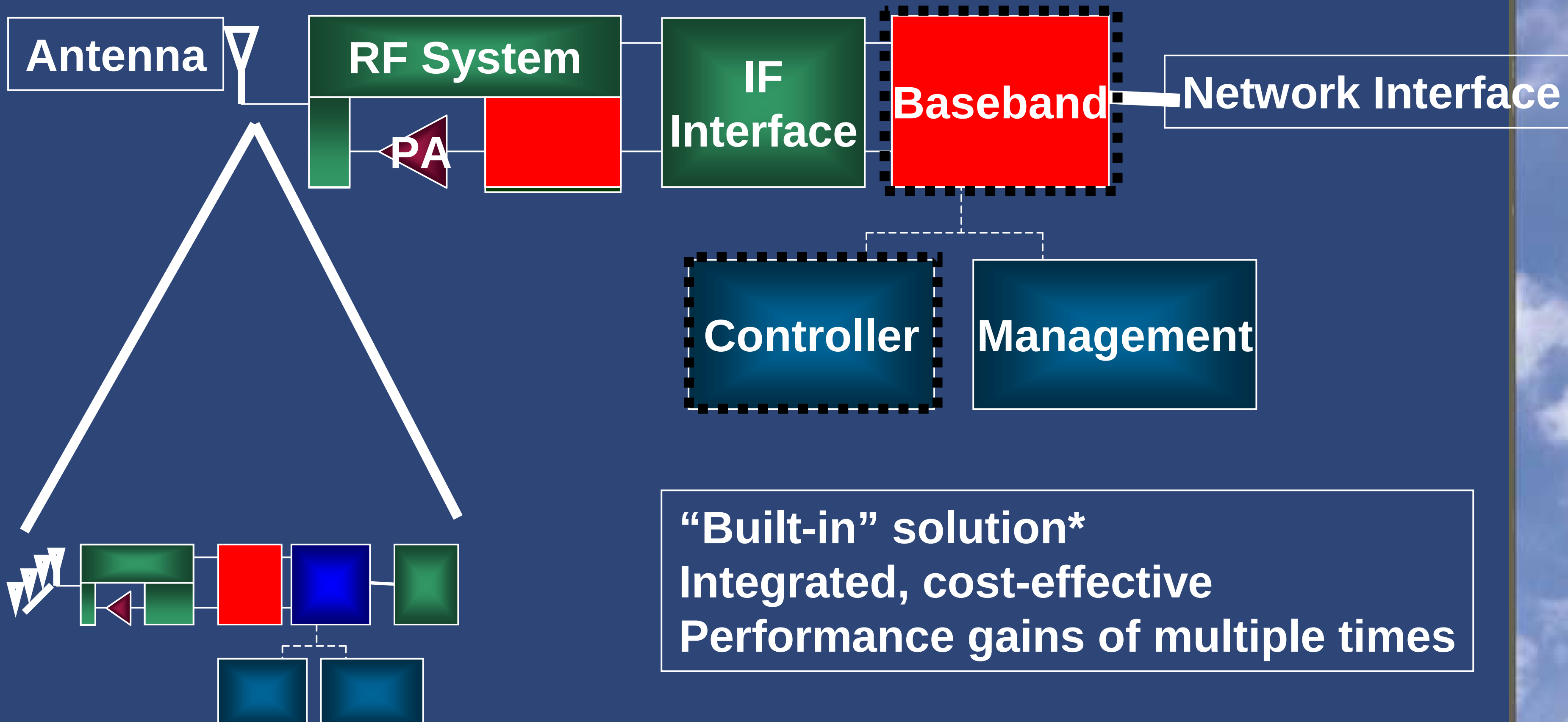
“Smart” Antenna Systems



(Taxonomy provided by Tom Marchok, Intel Capital
AA: Adaptive Antennas)

ArrayComm

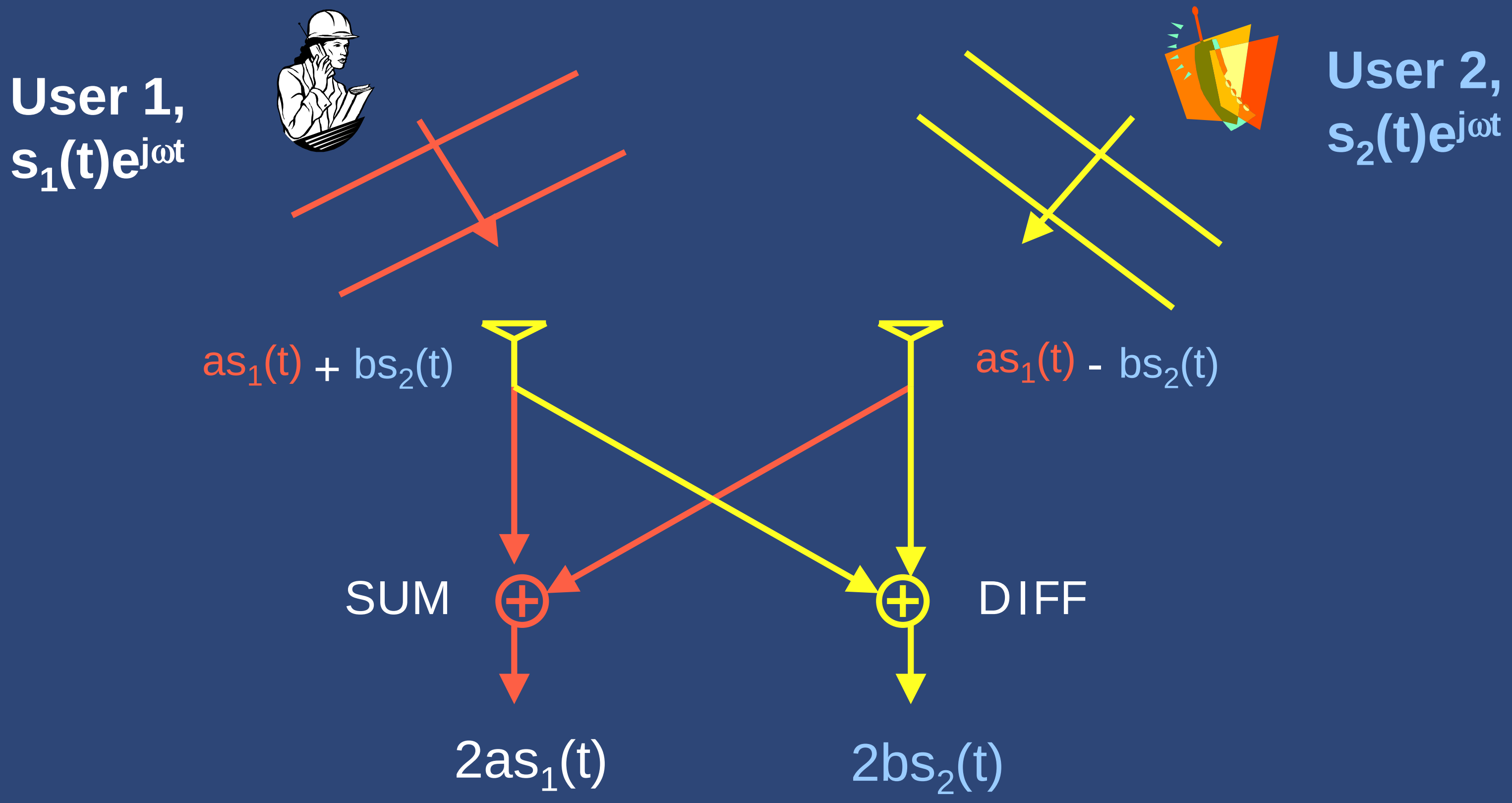
Base Station Architecture for Adaptive Antennas



“Bolt-on” solution (beamforming)
Costly: Performance gain < tens of %

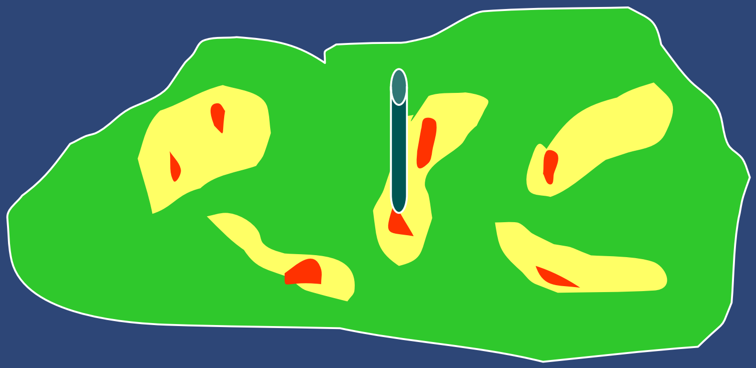
* *Moore’s Law is critical*

Adaptive Spatial Processing Concepts

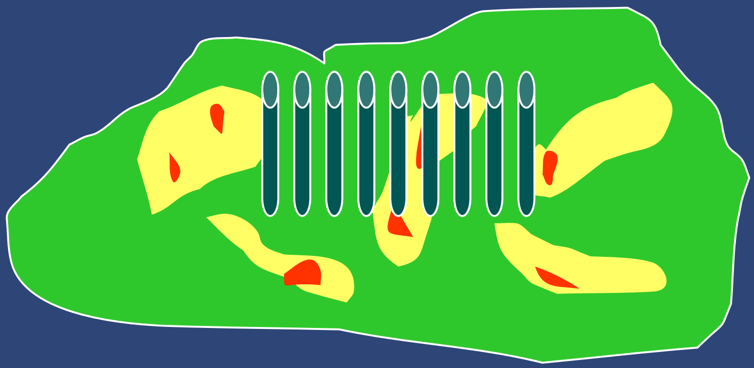


- **Users' signals arrive with distinct relative phases, amplitudes**
- **Signal Processing provides gain and interference mitigation**
- **Multiple Antennas raise performance gains**

Fading Adjustments



Single element in fading

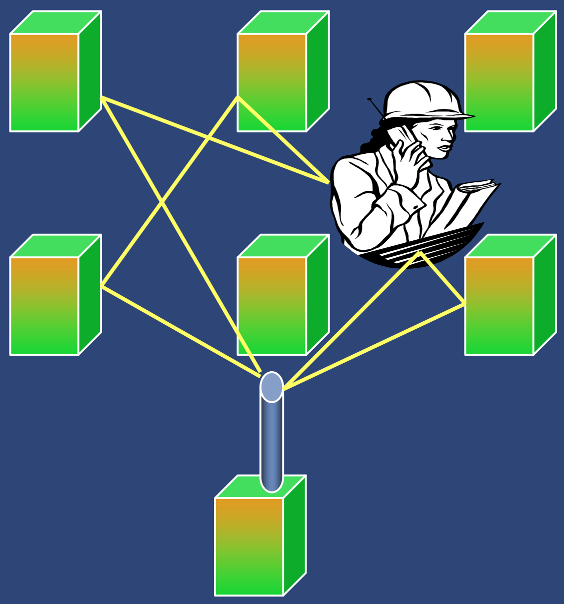


Array in fading

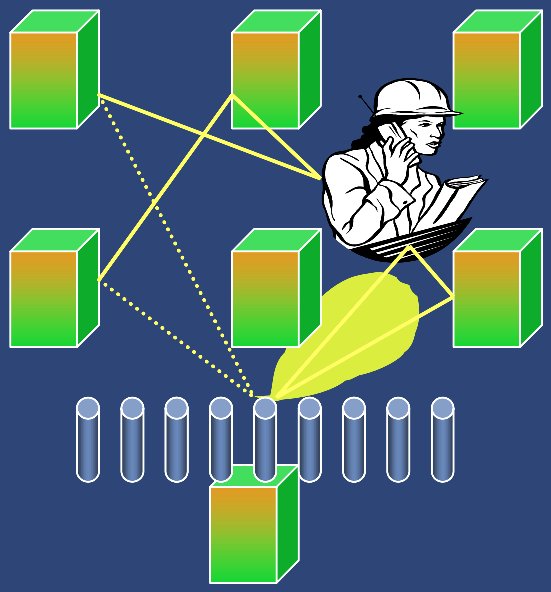
- Array diversity reduces fading margin
- 8-16 dB improvement for 10 element array

ArrayComm

Multipath Adjustments In non-LOS and cluttered environments



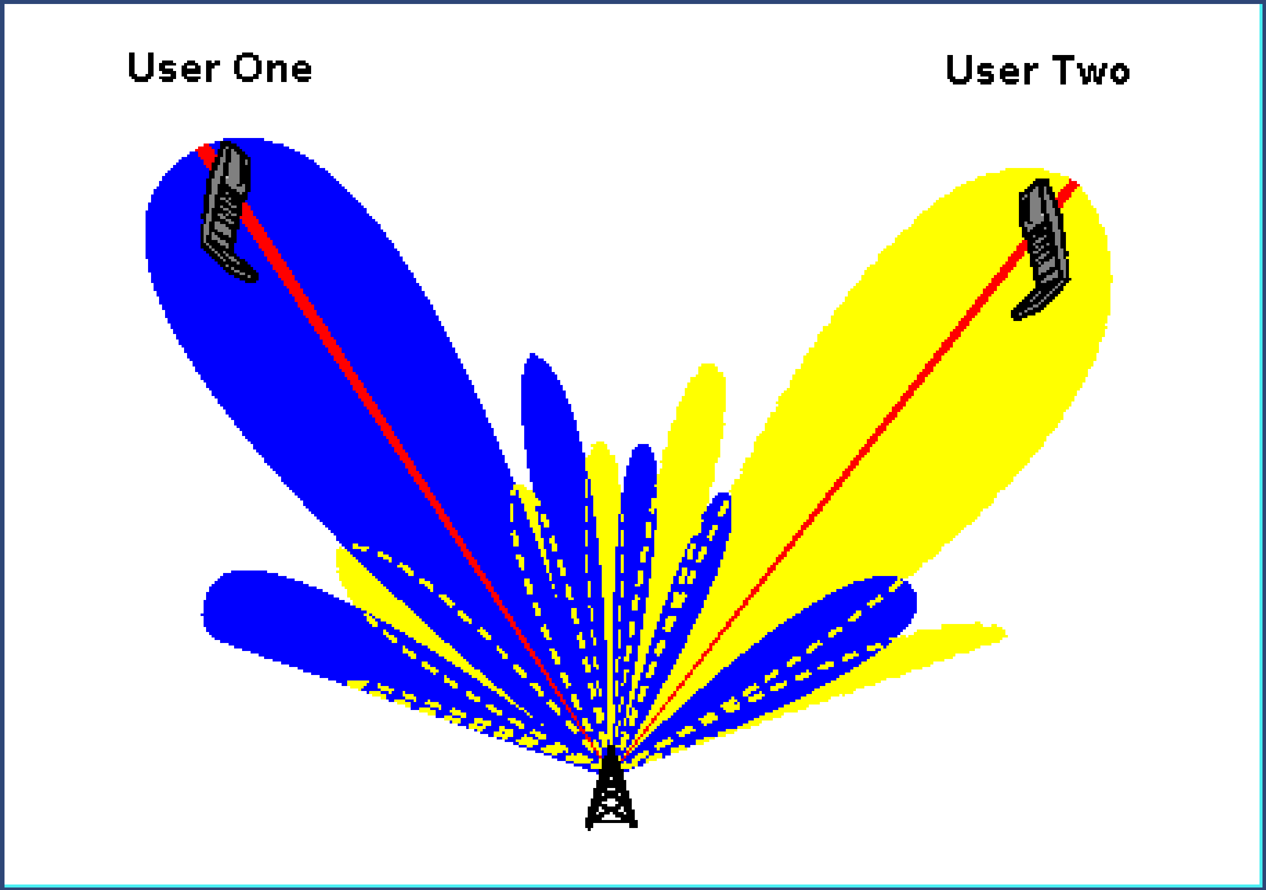
Single element multipath



Antenna array multipath

- Adaptive Antennas eliminate uncorrelated multipath
- Simplifies equalizer design

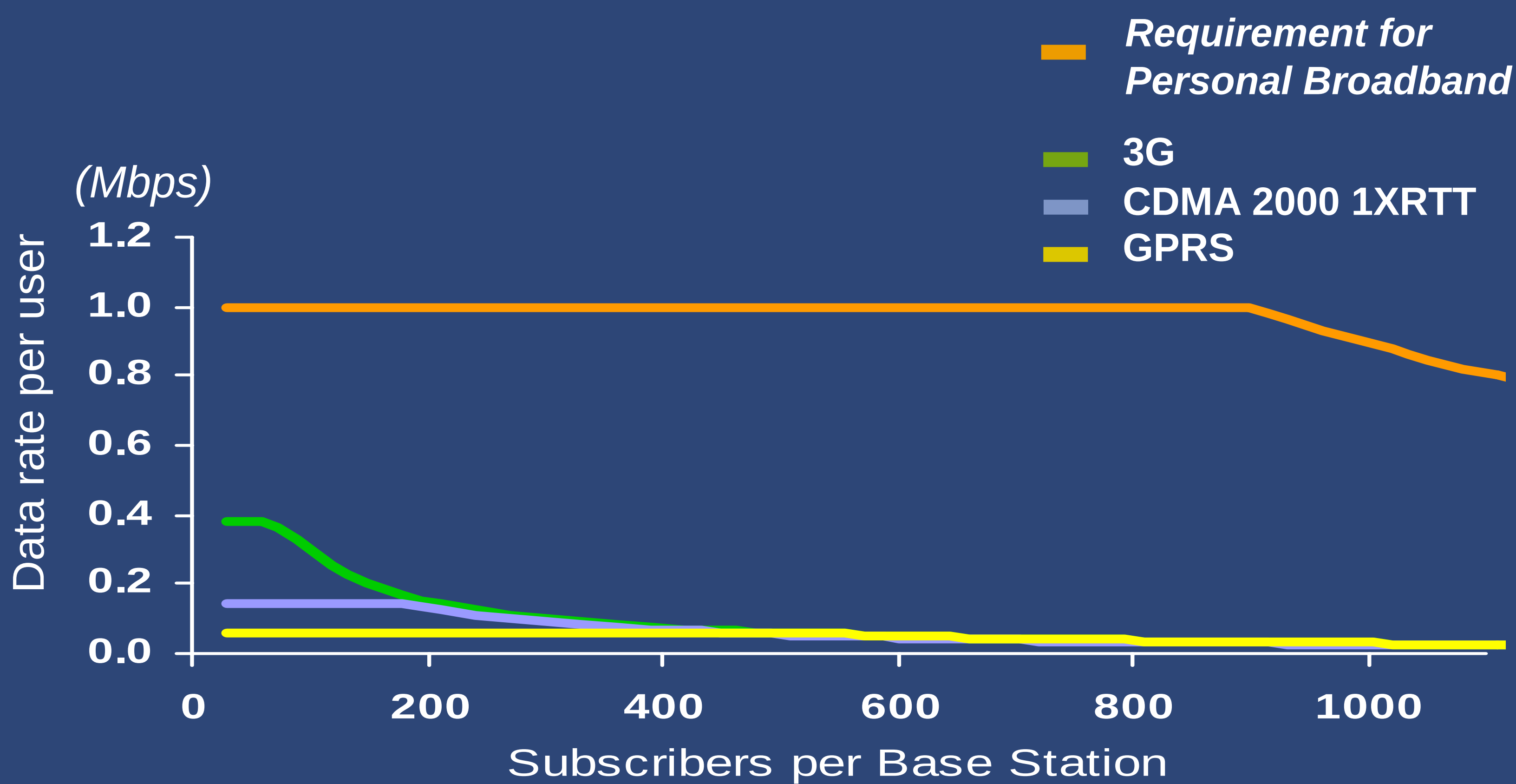
Spatial Channels: Supporting Two Users on the Same Channel in the Same Cell



- Frequency Re-use drops below 1, and approaches 1/3
- Spectral efficiency rises to > 4 b/Hz/s/cell
  in a loaded multi-cell network

ArrayComm

Performance Requirements for Broadband



Go to Backup

Source: Qualcomm, Ericsson, ArrayComm, 2002

Adaptive Antenna Technology in the DDI-Pocket PHS network

3 Million Users > 850,000 data-only subscribers

ARPU $52/mo

PHS Service Pricing

Data

32 kbps Unlimited Use	$32/mo
128kbps Unlimited Use	$72/mo

E-mail

P-mail (<20 chars)	$0.07 ea
Light mail (<45 chars)	$0.07 ea
DX mail (<2000 chars)	$0.08 ea

Other

Location look up	Varies
Music download	$0.11/min +song fee
Digital picture exchg	Airtime chg

PHS Devices

Honda Electron Data card

Fujitsu laptop w/imbedded PHS

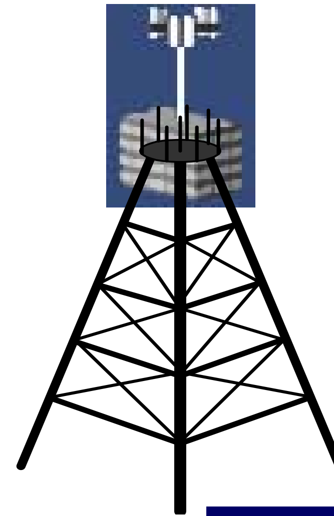
Kyocera Bluetooth adapter

Sanyo handset w/ MP3 player

Sanyo color handset

PHS Base Stations

30,000 DDI PHS Base Stations w/ IntelliCell®



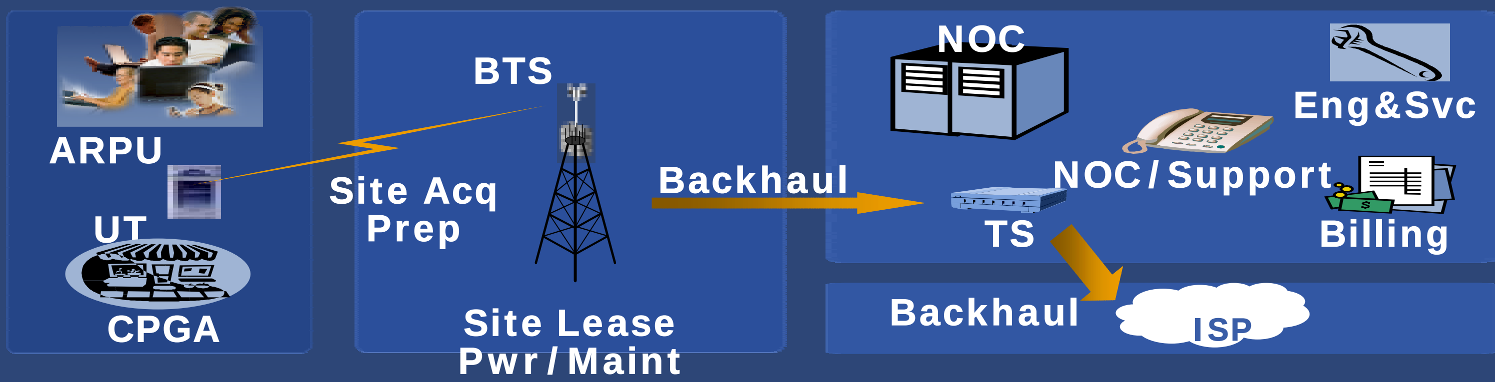
DDI POCKET   NTT Communications

Year	1997	1999	2002
PHS Data Access Speed w/ IntelliCell	32 kbps	64 kbps	128 kbps

Wireless Network Economics

- **COST ELEMENTS:**
  - **Spectrum**
    - (FDD vs TDD: > 100:1 ratio for $/MHz-POP)
  - **Radio access network**
  - **Network infrastructure**
  - **Management, billing, provisioning and services**
  - **End user equipment**
  - **Customer acquisition, installation and marketing**

Unit Economics of a Wireless Network

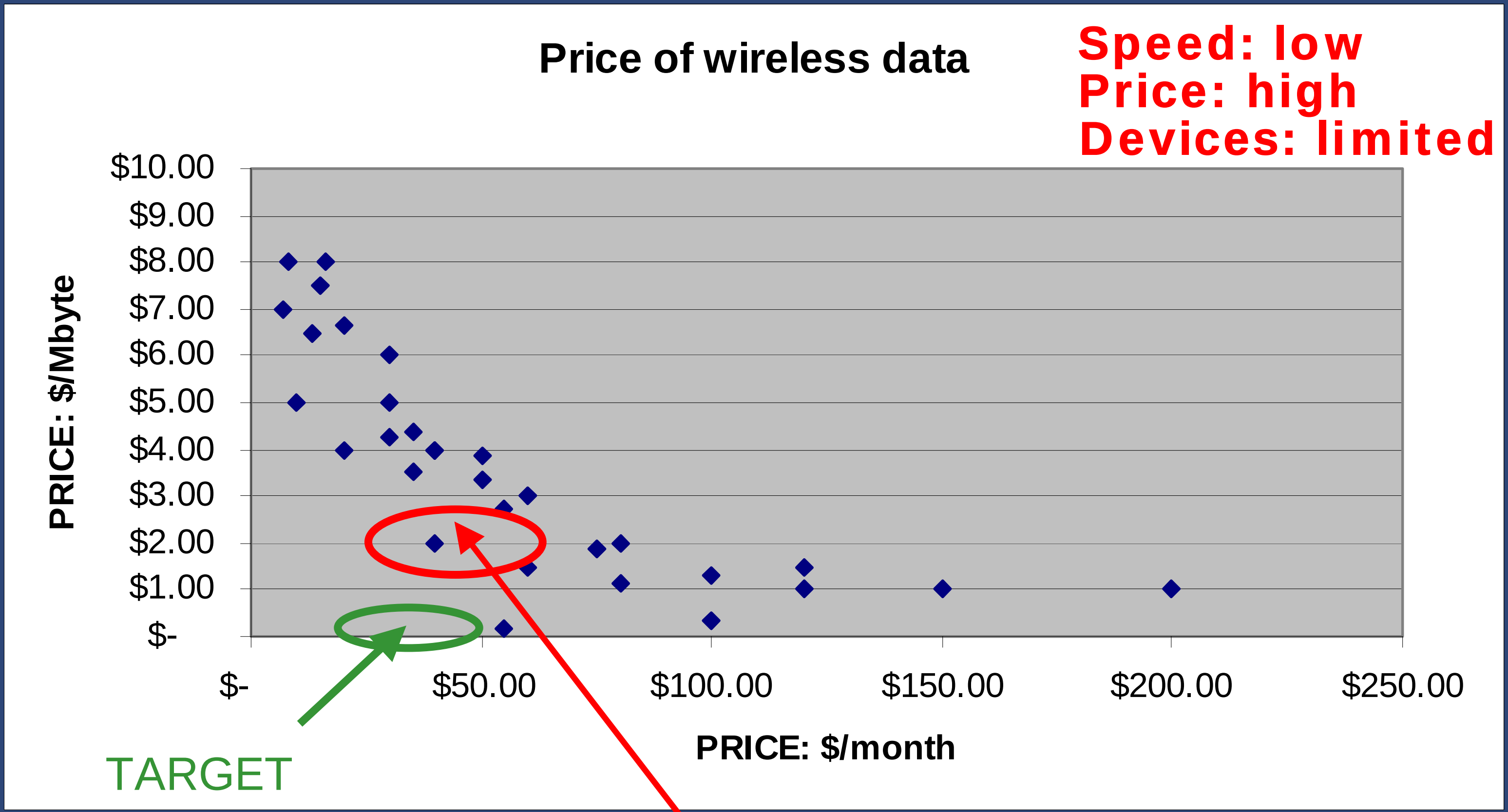


Covered Population	Direct Costs per month	# of Subs to reach Break Even	max # subs Total Capacity	% Network Utilization at breakeven
Cell range	Network Economics	System capacity and user price	System capacity	Efficiency of capital in the network

- Why 3G cannot compete with DSL/Cable*
- Why W-LANs do not scale**
- Why a new solution is required

*NTT-DoCoMo
**The Shosteck Group
-"Lemmings Jumping Off WLAN Cliff"

Price of Wireless Data Services



We pay $ 2.50/Mbyte for voice AND wireless data today

We pay < $ 0.20/Mbyte for wired Internet service

We *expect* to pay $ 40/month for > 100 Mbytes/month

Source: current US cellular and PCS wireless data pricing plans

Spectral Efficiency: Yesterday, Today and Tomorrow

- Legacy systems have spectral efficiency ranges of 0.01 to 0.2 b/Hz/s/cell
  - Should we put metrics in place to benchmark this?
- If we were to provide "broadband" vs voice services using the same benchmark, we would have to devote > 500 MHz of new spectrum for even a few % subscriber penetration
- Improvements in spectral efficiency of today's systems lower costs, improve performance, and grow existing businesses
- Greater than ten-fold increase in spectral efficiencies (over 3 b/Hz/s/cell) are needed to meet the market needs of new (Personal Broadband) Services
- Adaptive Antennas are KEY to achieve this performance