Performance Evaluation of 3G CDMA Networks with Antenna Arrays

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Background

- The 2G CDMA IS-95A cellular network has been deployed for eight years. Although the system design rules and operating procedures for voice services are well established and understood, these rules and procedures need to be re-examined in light of several technology innovations.
  - **Launching of cdma2000 1x high-rate data services***
  - **Interference cancellation****
  - **Antenna array**
  - **Multiple-input multiple-output (MIMO)**

*D. J. Shyy, "Impact of deploying cdma2000 data to voice capacity using cellular simulator," *OPNETWORK Conference*, Aug. 2002.

**D. J. Shyy and J. Dunyak, "Evaluation of interference cancellation technique in CDMA networks," *OPNETWORK Conference Distinguished Paper Award*, Aug. 2003.

Objectives

- We have built a 3G cdma2000 1x cellular simulator to investigate various design issues of cdma2000 1x networks.
  - **Simulate the physical layer using MATLAB**
  - **Simulate the networking layer, call processing and system aspects using OPNET Modeler**

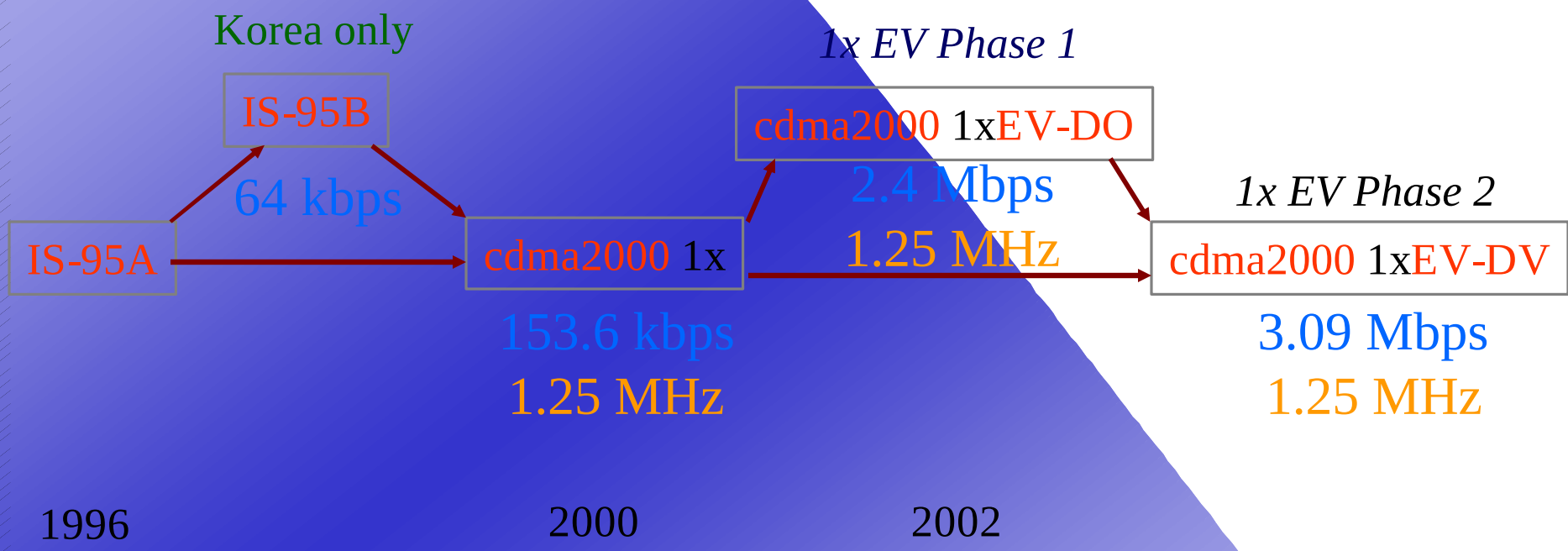
- In this paper, we investigate the effectiveness of deploying antenna arrays in CDMA networks using cdma2000 1x cellular simulator.

US Cellular Service Providers and Their Deployed Technology

	cdma2000 1x	cdma2000 1x EVDO	GSM/GPRS (TDMA)	IS-136 (TDMA)	i-DEN (TDMA)	W-CDMA
AT&T			x	x		x
Cingular			x	x		
Monet Mobile Networks	x	x				
Nextel					x	
T-mobile			x			
Verizon	x	x				
Sprint PCS	x	x				

*Note: In December 2002, AT&T Wireless and DoCoMo announced an agreement to work together to launch four U.S. markets using W-CDMA by the end of 2004. In July 2004, W-CDMA has bee deployed in the following 4 US cities: Detroit, Phoenix, San Francisco and Seattle.

CDMA IS-95 Evolution Path



What is the Drive for 3G?

- **Achieve higher voice capacity than 2G systems (at least double)**
- **Support high-rate data services**
  - *However, it is not sure where the 3G market is and what the killer applications are? Wireless Internet? Camera photos? Streaming audio and video? Location service? In addition, Wi-Fi (WLAN) hot spots are taking over 3G data market in a fast pace.*
  - *As a result, US operators are not counting on data applications. Instead, US operators are counting on the superior voice capacity.*
- **Better spectrum efficiency**
- **Seamless global roaming (does not seem to be possible any more)**

IMT-2000

- **International Mobile Telecommunications-2000 (IMT-2000) is the 3G standards in International Telecommunications Union (ITU)**
  - In Europe, 3G is also referred as Universal Mobile Telecommunications System (UMTS)
  - 2000 referred to both the frequency band (2 GHz) and the expected deployment date (year 2000)
- **Data rate capabilities**
  - 144 Kbps for vehicular (macro cell)
  - 384 Kbps for pedestrian (micro cell)
  - 2 Mbps for fixed (pico cell)

3G Standards

- **On 11/05/99, ITU Radio Communication Sector (ITU-R) Task Group 8/1 endorsed 3 modes for IMT-2000 standards:**
  - Multi-carrier (MC) FDD
    - IMT-MC
    - cdma2000 1x and 3x for radio access network
  - Direct Spread (DS) FDD
    - IMT-DS
    - W-CDMA FDD for radio access network
  - Direct Spread (DS) TDD
    - IMT-TC
    - W-CDMA TDD for radio access network
    - Mainly in China

Comment: 3 modes actually mean 3 standards.

Maximizing Radio Capacity for 3G

- **The fundamental bottleneck of a 3G network is still in the radio access network, not in the core network. As a result, capacity optimization of the radio access network is most important.**
  - Conserving the usage of spectrum is the top priority for US cellular service providers because some of the providers have only 5 MHz of spectrum
- **IS-95 voice capacity per cell**
  - 20 – 25 users
- **cdma2000 1x voice capacity per cell**
  - 35 – 40 users

Methods of Increasing Radio Capacity

- cdma2000 1x enhancements
- Interference cancellation
- Smart antenna
- Multiple-input multiple-output (MIMO)

Evaluate the Capacity Improvement using Antenna Array at the BS

- MATLAB Models
- Antenna Array Models
- OPNET Models

MATLAB Models

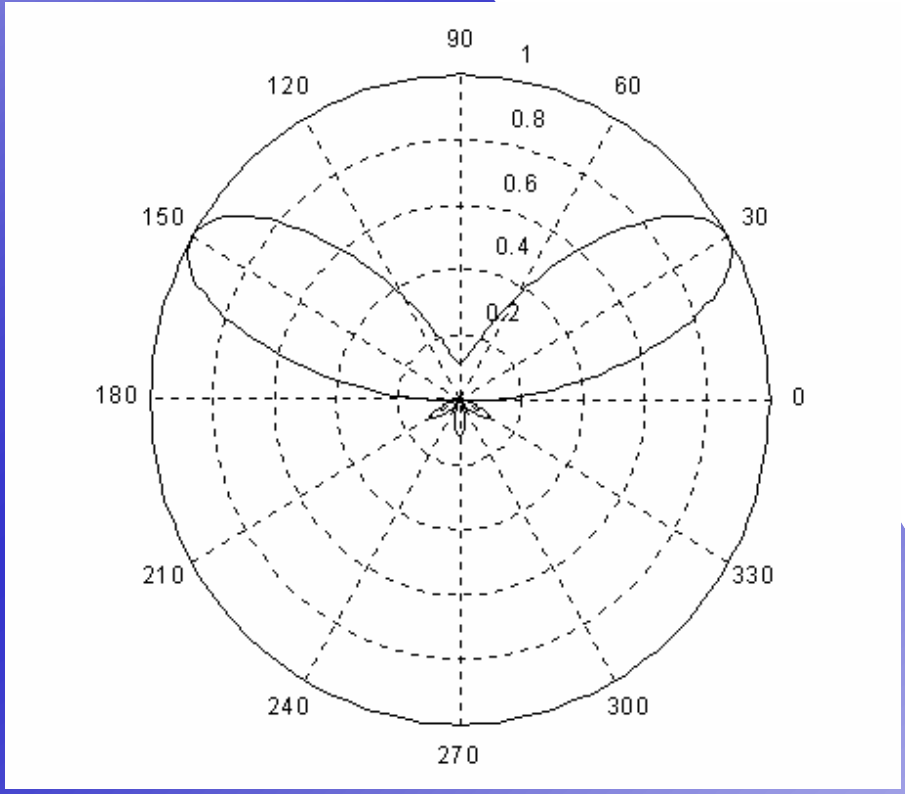
- Derive the E_b/N_t for forward and reverse links

Antenna Array Models

- **A standard linear equally spaced (LES) array is considered. The distance *d* between the elements of the LES array is half of the carrier wavelength.**
- **The overhead channels (pilot, paging and sync) are sent over the common omni-directional antenna. The traffic channel is sent over the individual beam pointing toward the user. The patterns of individual beams are the same except the direction is different.**

Array elements	Main lobe beamwidth	Main lobe gain	Side lobe beamwidth	Side lobe gain
1	360^0	17.1 dB	N/A	N/A
2	138^0	17.1 dB	222^0	11.3 dB
4	76^0	17.1 dB	284^0	7.8 dB
6	54^0	17.1 dB	306^0	5.9 dB

An Example of Antenna Gain Pattern: 3 Elements



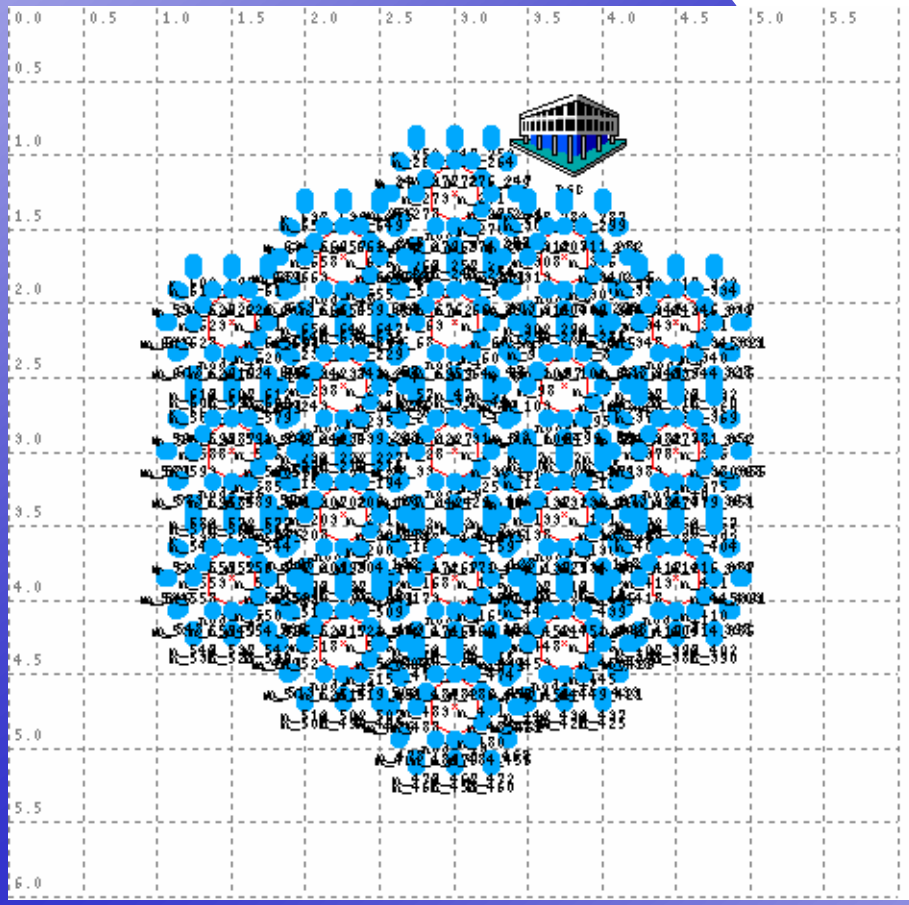
OPNET Models

- Forward link and reverse link (Downlink and uplink)
- Pilot, paging and sync channels
- Fundamental channels
- Supplemental channels
- Soft handoff procedures and messaging
- Power control for forward and reverse links
- Admission control for forward and reverse links
- Computation of same-cell interference, other-cell interference, and noise for both forward and reverse links

Network Configuration

- **1 Base Station Controller (BSC)**
- **19 omni-directional cells**
  - Statistics are collected only for the center cell. The other cells are used to provide realistic interference condition.
- **836 mobiles**
- **Cell antenna height: 30 m**
- **BS max. power: 16 W**
- **PCS frequency band (1900 MHz)**
- **Propagation model: Extended HATA**
- **In-building penetration loss: 15 dB**
- **Cell radius: 675 meter (derived from RF link budget)**

OPNET Network Layout



Simulation Results I: Voice Capacity Comparison

- **The voice service uses Rate Set 1, i.e. 9.6 kbps. The required Eb/Nt to achieve the target FER 1% for the forward voice channel is 7 dB.**

Array elements	Strongest serving cell is cell 0	Serving cells include cell 0
M=1	22	27
M=2	26	38
M=4	29	51
M=6	34	63

Simulation Results II: Always Available 153.6 Kbps Data

- **Beamforming is used to compensate for the difference in processing gain when supporting different data rates. As a result, the users can always enjoy high-rate data service regardless of the location. At the BS, the forward transmit power required to support 153.6 kbps SCH can be computed assuming the data rate is 9.6 kbp.**

Array elements	Number of users (strongest serving cell is cell 0)	Number of users (serving cells include cell 0)
M=1	N/A	N/A
M=2	N/A	N/A
M=4	N/A	N/A
M=6	32	60

Simulation Results III: Dynamic Handover Thresholds Adjustment

- **Since the interference is reduced using antenna array techniques, the pilot Ec/Nt seen by the user also becomes stronger. As a result, more users are in 2-way and 3-way soft handoff. The voice capacity can be further improved if the soft handoff thresholds are optimized (e.g. increase T_ADD)**

Array elements	Number of users (strongest serving cell is cell 0)	Number of users (serving cells include cell 0)
M=1	N/A	N/A
M=2	27	36
M=4	36	49
M=6	42	59

Conclusions

- **With the help of the cellular simulator, we conclude that the network capacity increase is proportional to the antenna array capability at the BS.**
- **When the BSs are equipped with antenna array, the network capacity is largely improved (almost doubled with a high enough number of array elements) compared to a network without antenna array.**
  - This finding is impressive since with the major enhancements from cdma2000 1x (such as improved coding gain, faster forward power control, and coherent demodulation for the reverse link), the capacity improvement of cdma2000 1x compared to IS-95 is only between 1.5 – 2 times

Recommendations

- **Our recommendations for deploying antenna array in the cdma2000 networks are to**
  - Balance the coverage of pilot channel and traffic channels
  - Deploy at least 6 array elements per antenna array to double the voice capacity
  - Use antenna array to perform QOS provisioning for high-rate data users, i.e., increase the coverage range for high-rate data connections.