Gigabit Wireless Techniques for 4G Mobile Communications Network

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OUTLINE

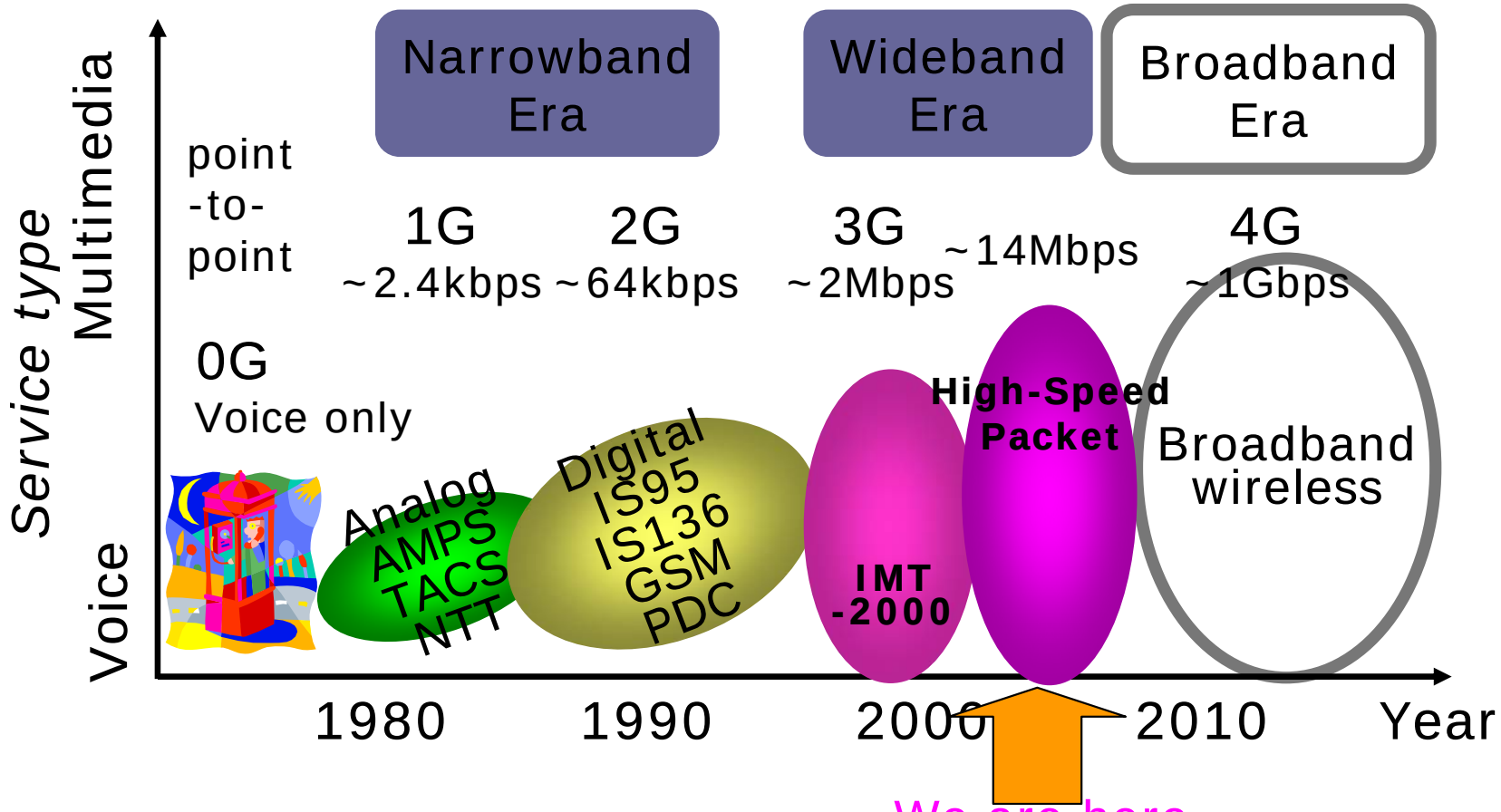
- Wireless Evolution:
  from Voice to Visual Communications
- Broadband CDMA
- High-Speed Packet Access
- Wireless Multihop VCN

Wireless Evolution

- From 2G to 3G
- Then into 4G: Visual Communications

Evolution Path

- Cellular systems have evolved from narrowband to wideband
- Now on the way to broadband wireless network



Internet Access

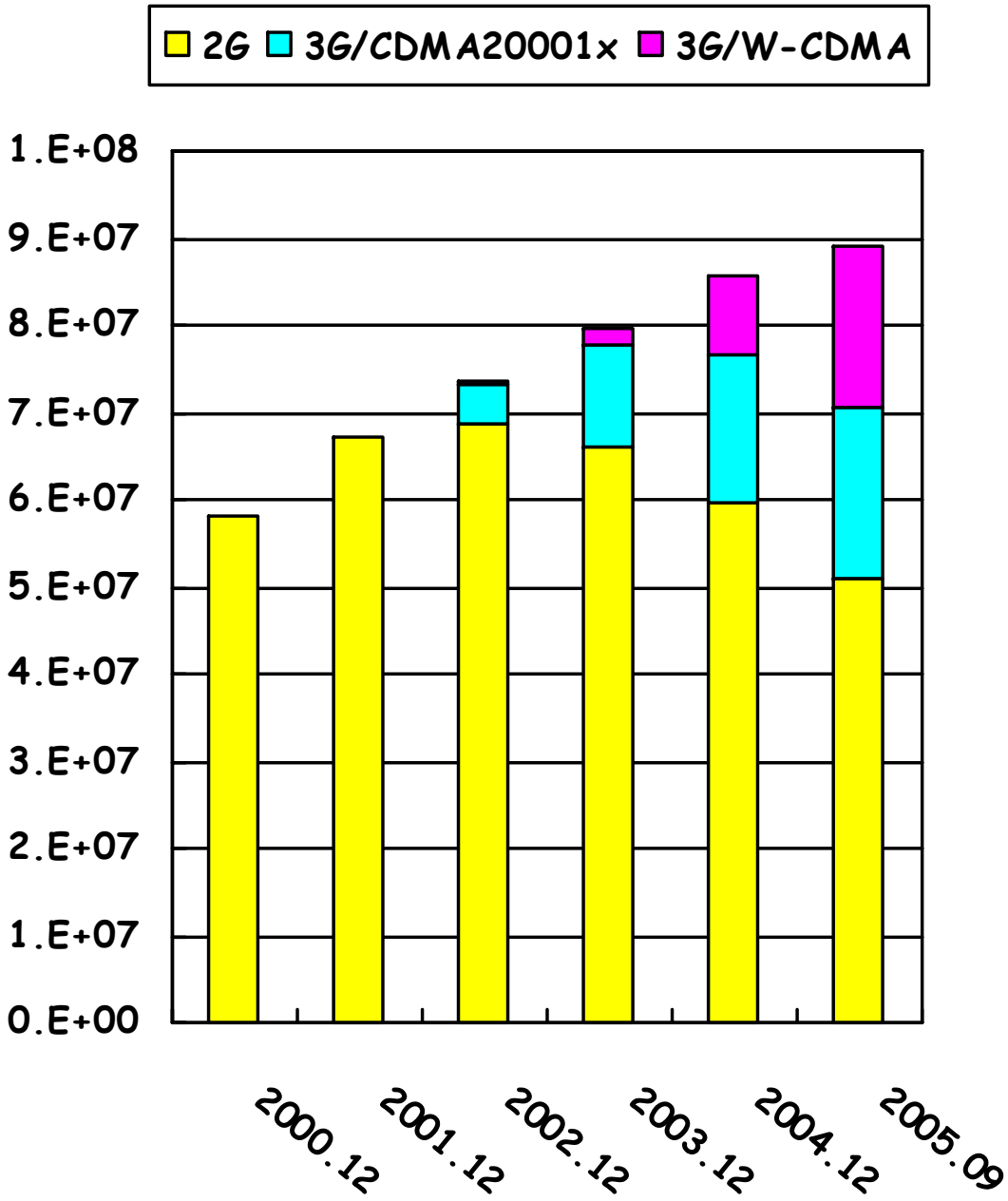
- Towards broadband multimedia services
  - In line with the increasing popularity of Internet in fixed networks, cellular systems are evolving from simply providing traditional voice commun. services to providing broadband multimedia services through Internet access
- Internet cellphones@ Sept. 2005 (source: TCA)
  - Total mobile (cellular+PHS) users:

    93.61m (penetration 73.4%)
  - Users connected to Internet: 76.22m (86.3%)
    - i-mode:45.00m
    - Ezweb:19.16m
    - Vodaphone live:12.79m

Shift To 3G Systems Is On Going

- Total No. of Cellular Subscribers
  - 89,126,800
- 2G (51,055,800)
  - PDC: 49,899,500
  - cdmaOne: 1,156,300
- 3G (38,071,100)
  - 41.6%
  - W-CDMA:18,523,700
  - CDMA2000 1x: 19,547,400

As of Sept. 2005

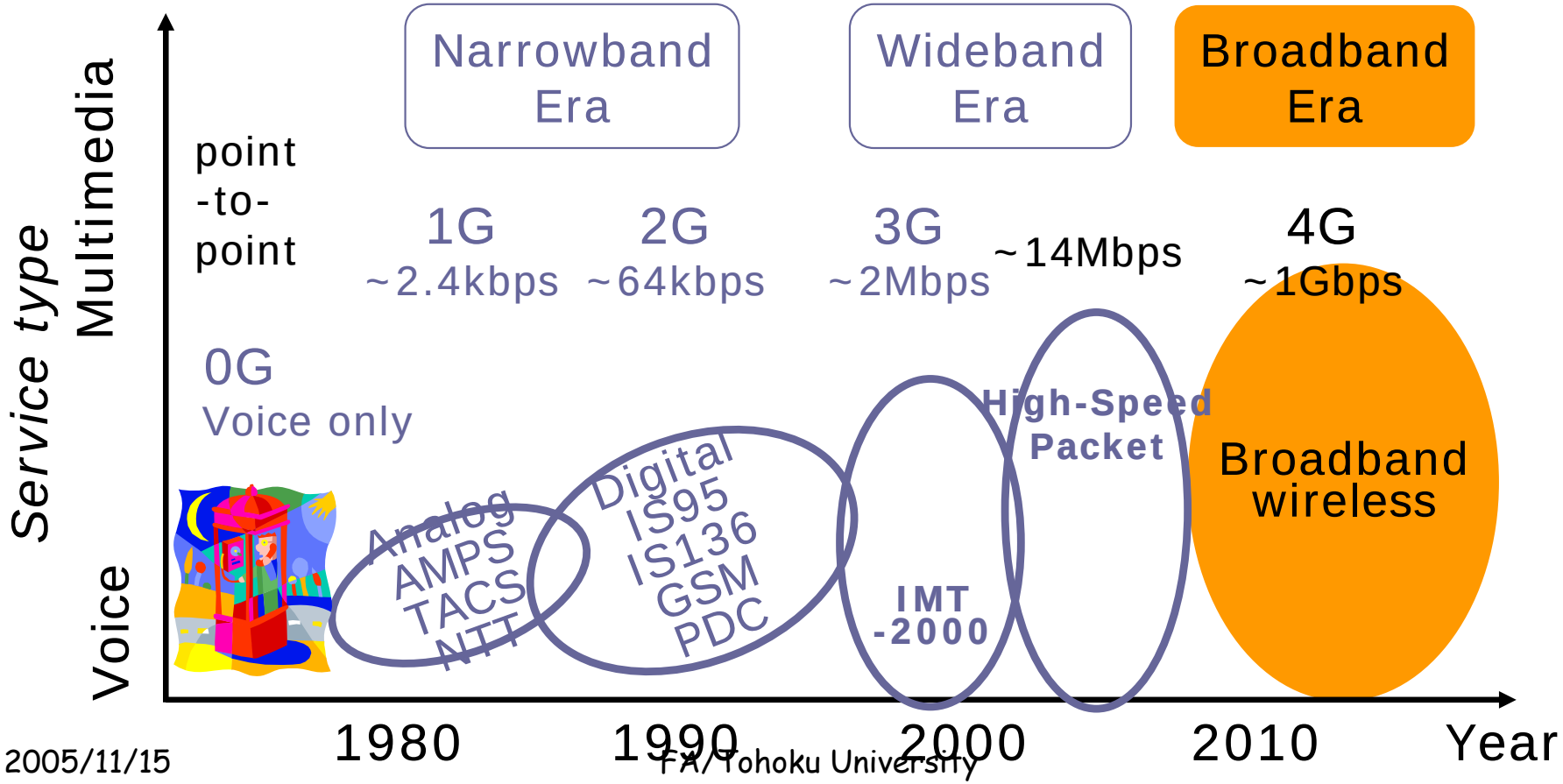


3.5G Systems Soon to Arrive

- Data transfer rates in 2G systems are too slow for retrieving rich information distributed in the Internet.
- 3G cellular systems are designed to offer cellular users a significantly higher data-rates services using wideband (5MHz bandwidth) DS-CDMA technology:
  - indoor: 2Mbps
  - pedestrian: 384kbps
  - vehicular: 144kbps
- WCDMA will continue to evolve to meet the demands for best effort packet data services and substantially strengthen its downlink data rate capability.
- High-speed downlink packet access (HSDPA) of ~14Mbps/5MHz will soon appear.

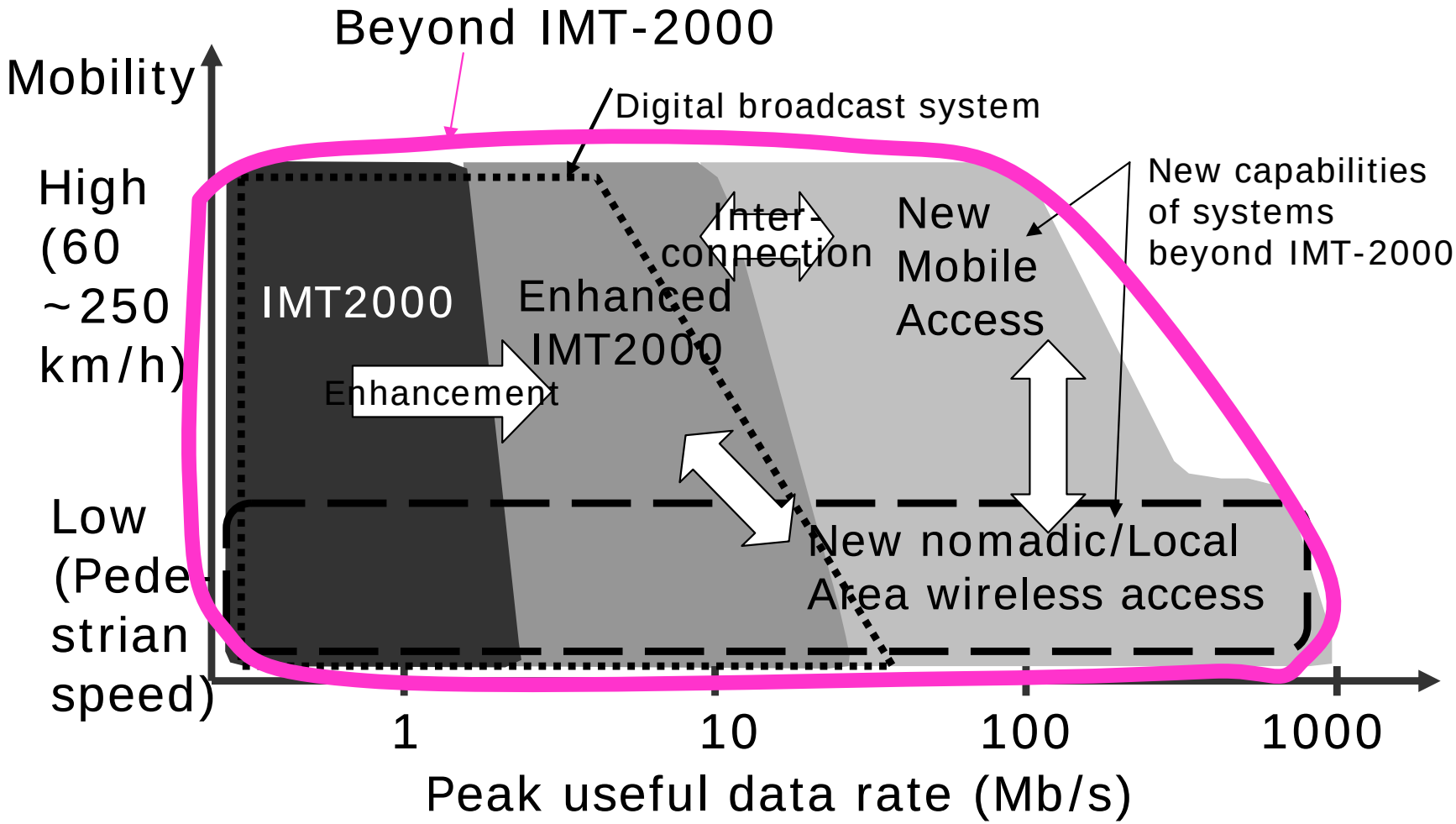
Evolution into 4G

- Demands for broadband wireless services (internet related) are increasing
- Even ~14Mbps data rate capability of 3.5G will sooner or later become insufficient



4G Vision

- ~1Gbps wireless access



ITU-R WP8F (Ottawa, June 2002) :
illustration of Capabilities of IMT2000 and Systems Beyond

What Is a Killer Application in 4G?

- It is quite difficult to predict which services will become popular in the coming 10 years
- However, it is no doubt that Internet related services will dominate in 4G
- Another promising service in 4G is wireless visual communication

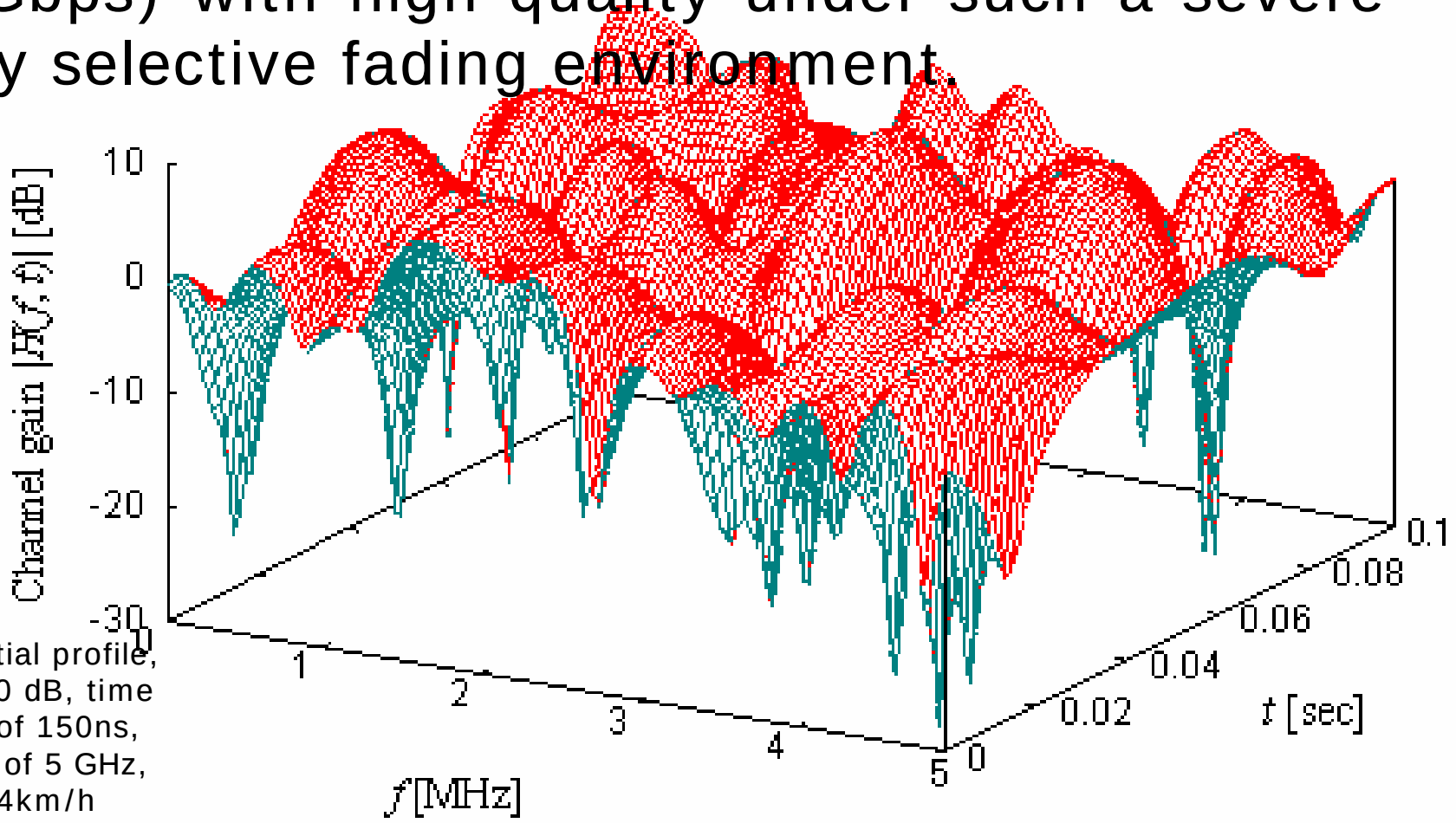
	1G	2G	3G	4G
Wireless Access	Analog	Digital	Digital	Up to 1 Giga bit/s
	FDMA	TDMA, DS-CDMA	DS-CDMA	OFDM, CDMA based access
Core-network	Circuit-switched	Circuit-and packet switched	Circuit-and packet - switched	Broadband IP-based
Major Services	Voice	Voice, data	Voice, video	??????

Broadband CDMA

- F. Adachi, D. Garg, S. Takaoka, and K. Takeda, “Broadband CDMA techniques,” IEEE Wireless Commun. Mag., Vol. 12, No. 2, pp. 8-18, April 2005.
- F. Adachi, T. Sao, and T. Itagaki, “Performance of multicode DS-CDMA using frequency domain equalization in a frequency-selective fading channel,” Electronics Letters, vol. 39, pp.239-241, Jan. 2003.
- F. Adachi and K. Takeda, “Bit error rate analysis of DS-CDMA with joint frequency-domain equalization and antenna diversity combining,” IEICE Trans. Commun., vol.E87-B, no.10, pp.2991-3002, Oct. 2004.

Channel Characterization

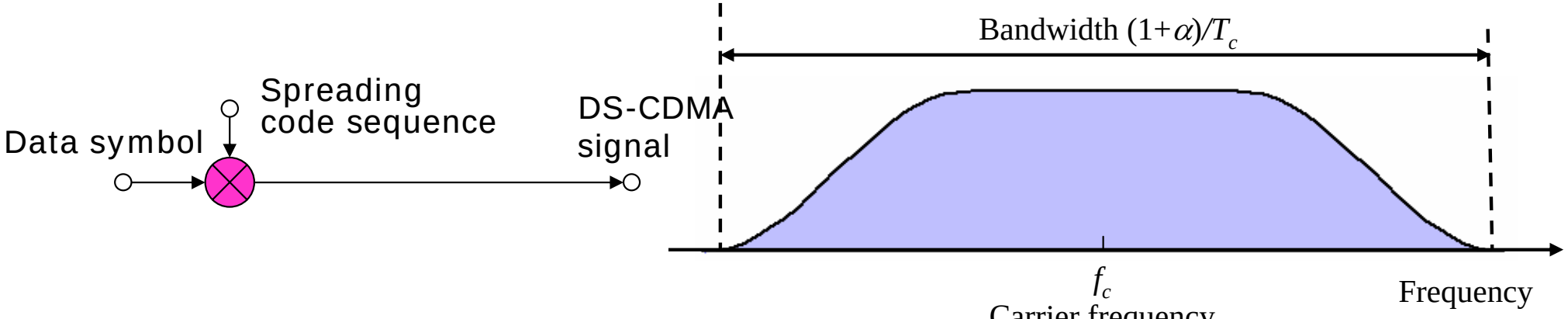
- Channel frequency response randomly varies both in frequency and in distance (or in time).
- Challenge is to transmit data at high speed (close to 1 Gbps) with high quality under such a severe doubly selective fading environment.



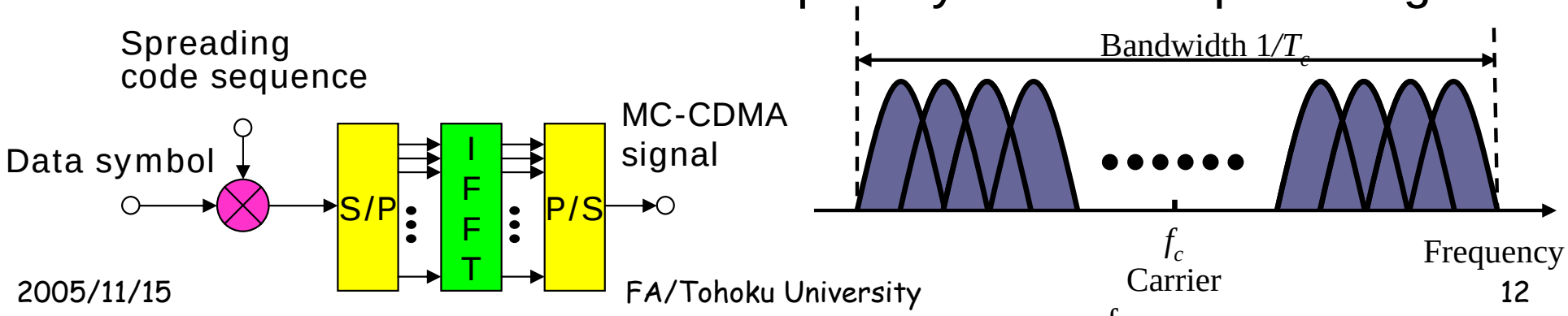
16-path exponential profile, delay factor of 1.0 dB, time delay separation of 150ns, carrier frequency of 5 GHz, moving speed of 4km/h

CDMA Techniques

- CDMA can overcome the channel frequency-selectivity and even improve the transmission performance, yet retaining multiple access capability
  - DS-CDMA: Time domain spreading
  - MC-CDMA: Frequency-domain spreading
- DS-CDMA: single-carrier/time-domain spreading

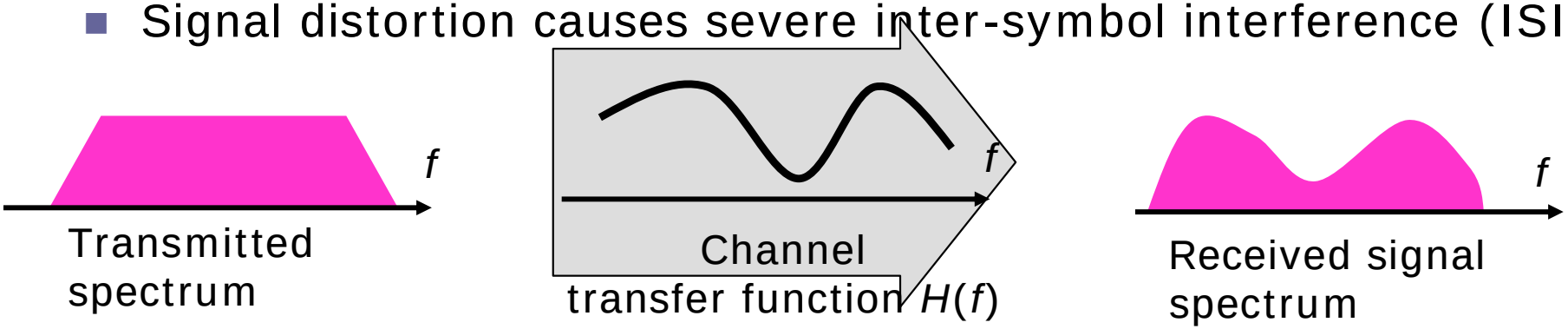


- MC-CDMA: multi-carrier/frequency-domain spreading



Myth

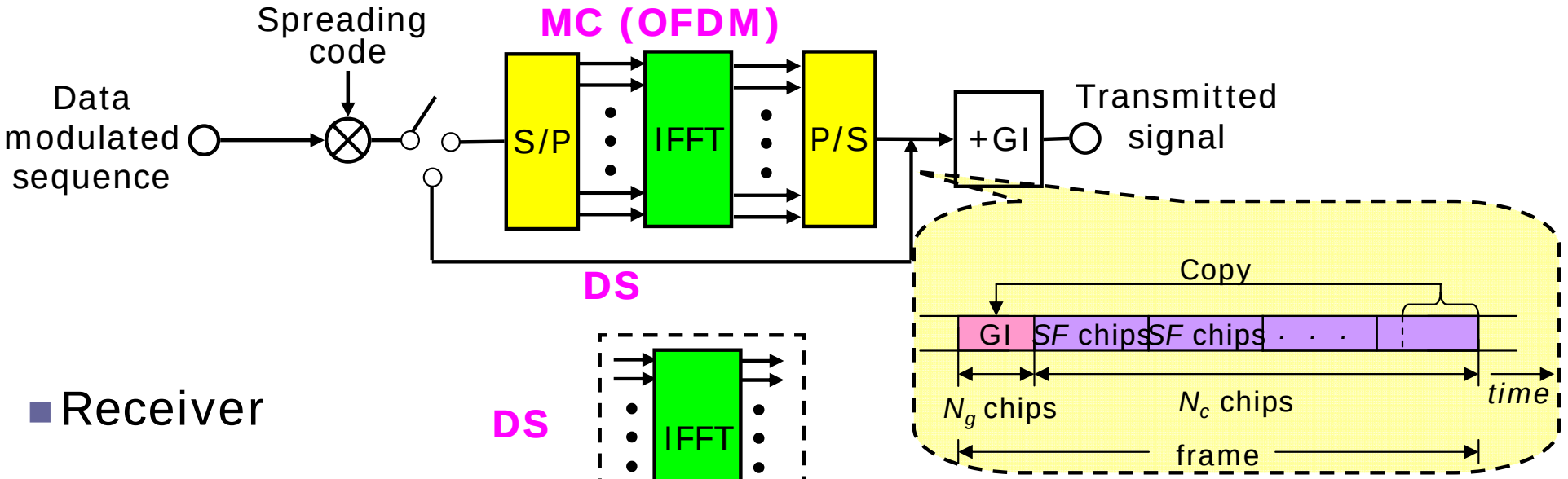
- Common belief
  - DS is a technique for 3G
  - MC has been considered the best candidate for the wireless access to overcome the frequency-selectivity of the channel
- Single-carrier transmission
  - Signal distortion causes severe inter-symbol interference (ISI)



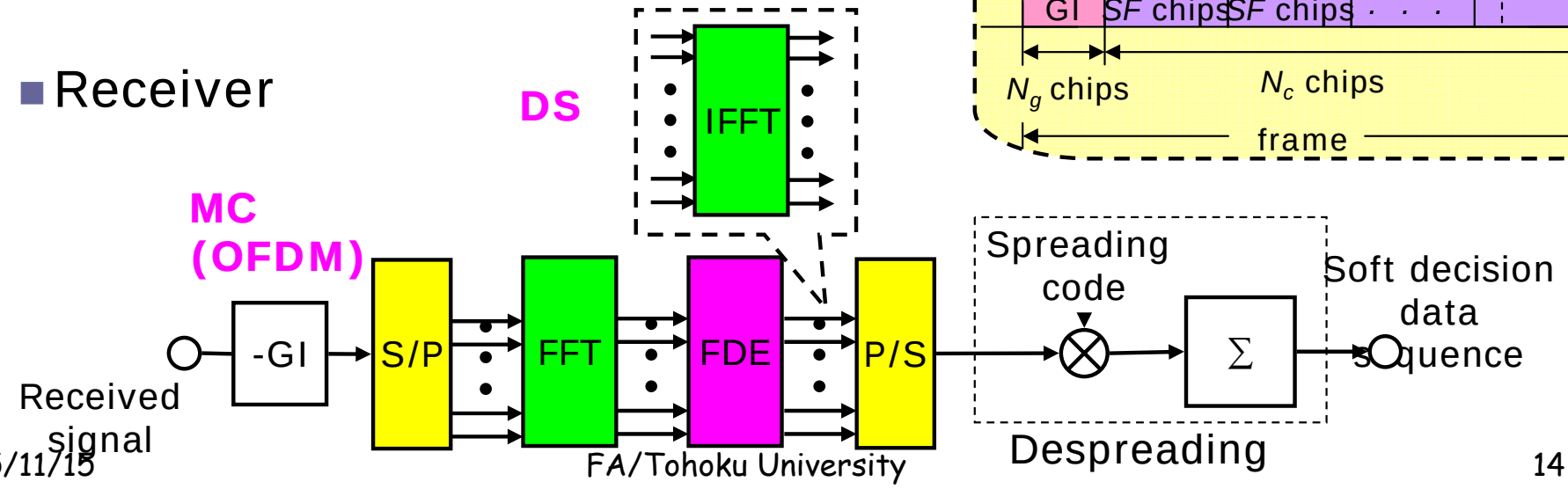
- Multi-carrier transmission
  - A number of narrowband orthogonal subcarriers is used to transmit high speed data in parallel
  - Each subcarrier experiences frequency nonselective fading and hence ISI is not produced

Realities

- With FDE, both DS- and MC-CDMA can exploit channel frequency-selectivity to improve the performance
- Transmitter/receiver structure is similar
  - Transmitter

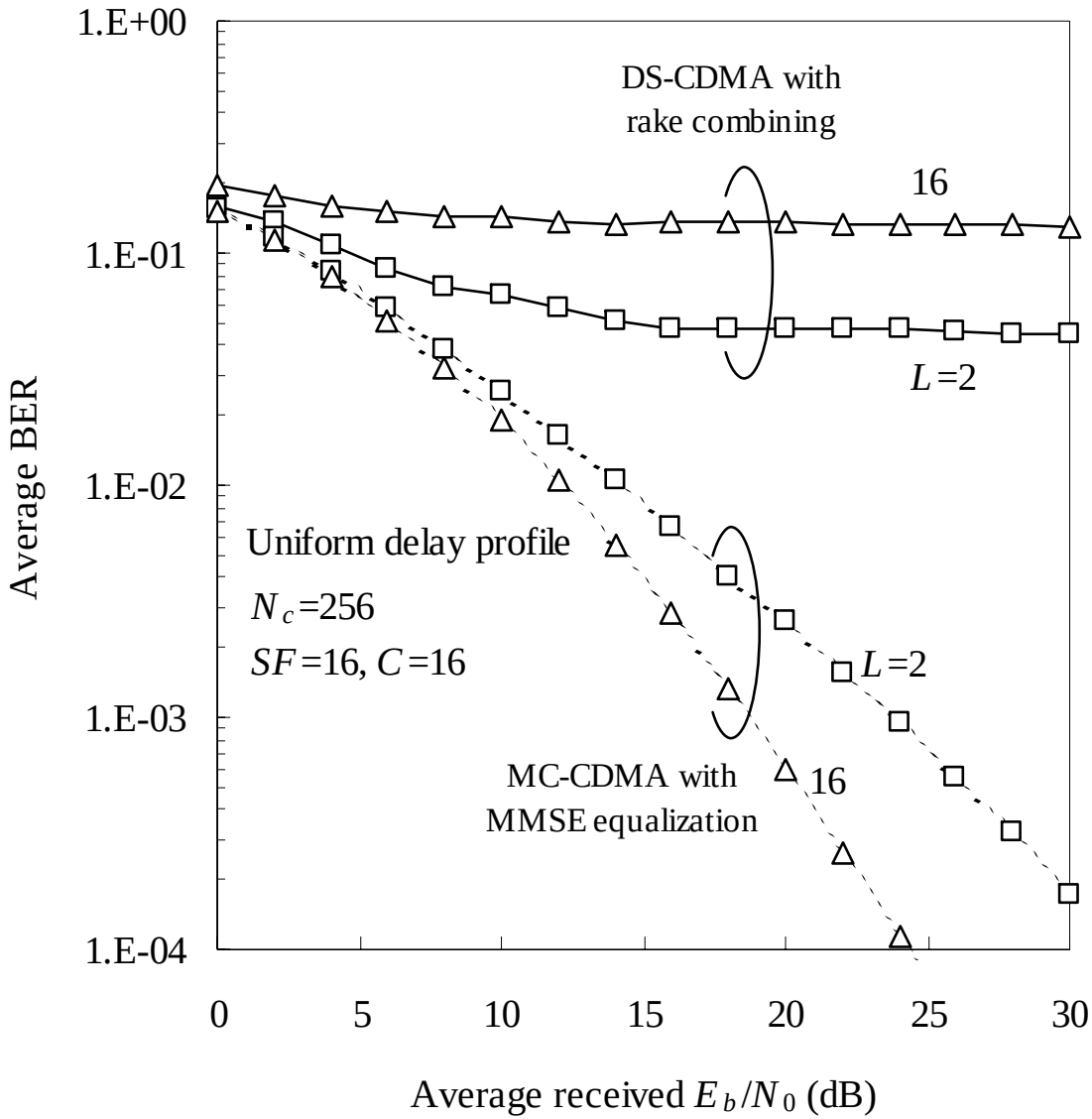


  - Receiver



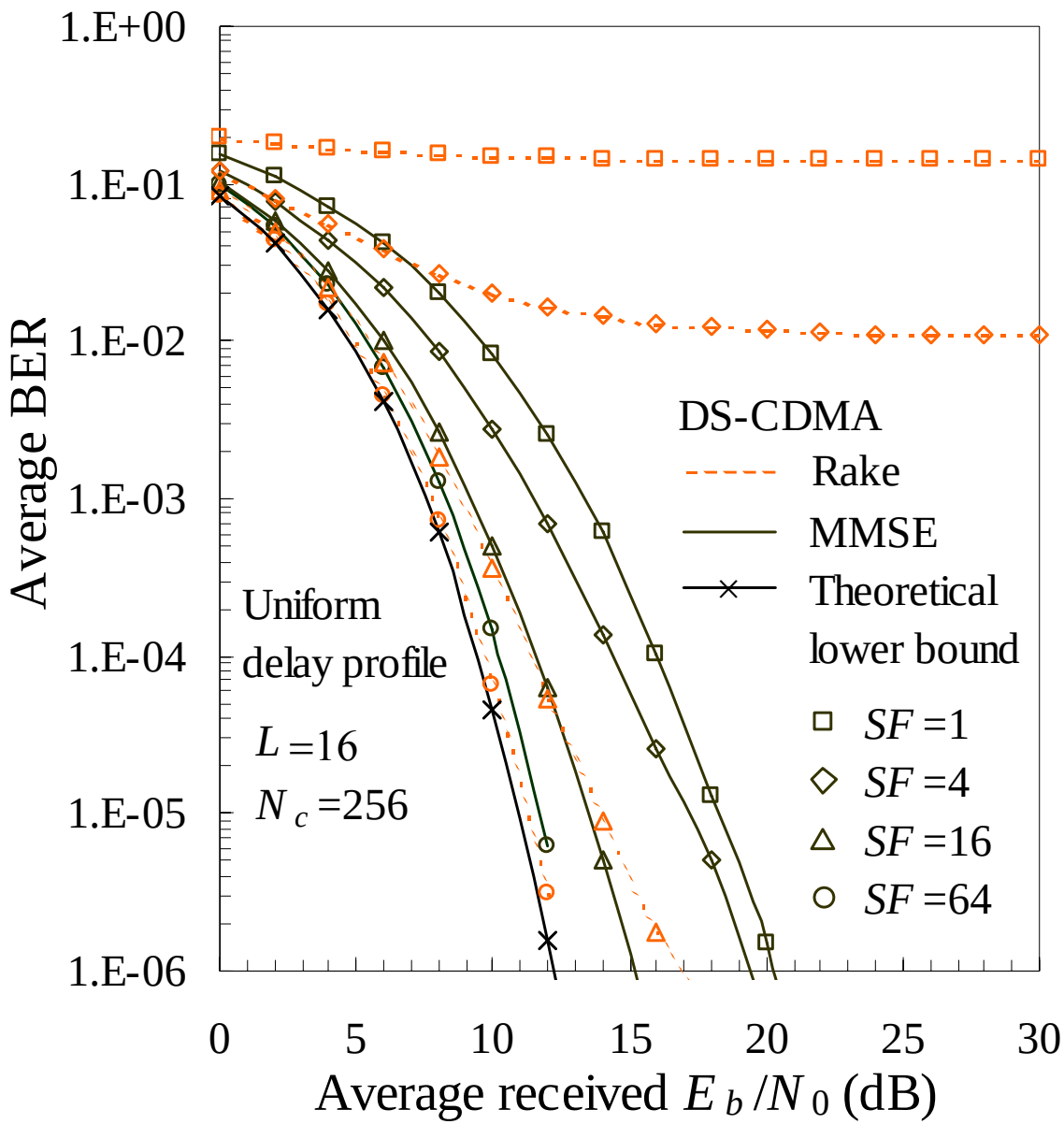
DS with Rake vs. MC with FDE

- Performance of DS-CDMA with Rake significantly degrades due to IPI
  - BER floor increases as the no. of paths , L, increases
- On the other hand, MC-CDMA with MMSE-FDE provides much better performance
  - Performance improves as L increases



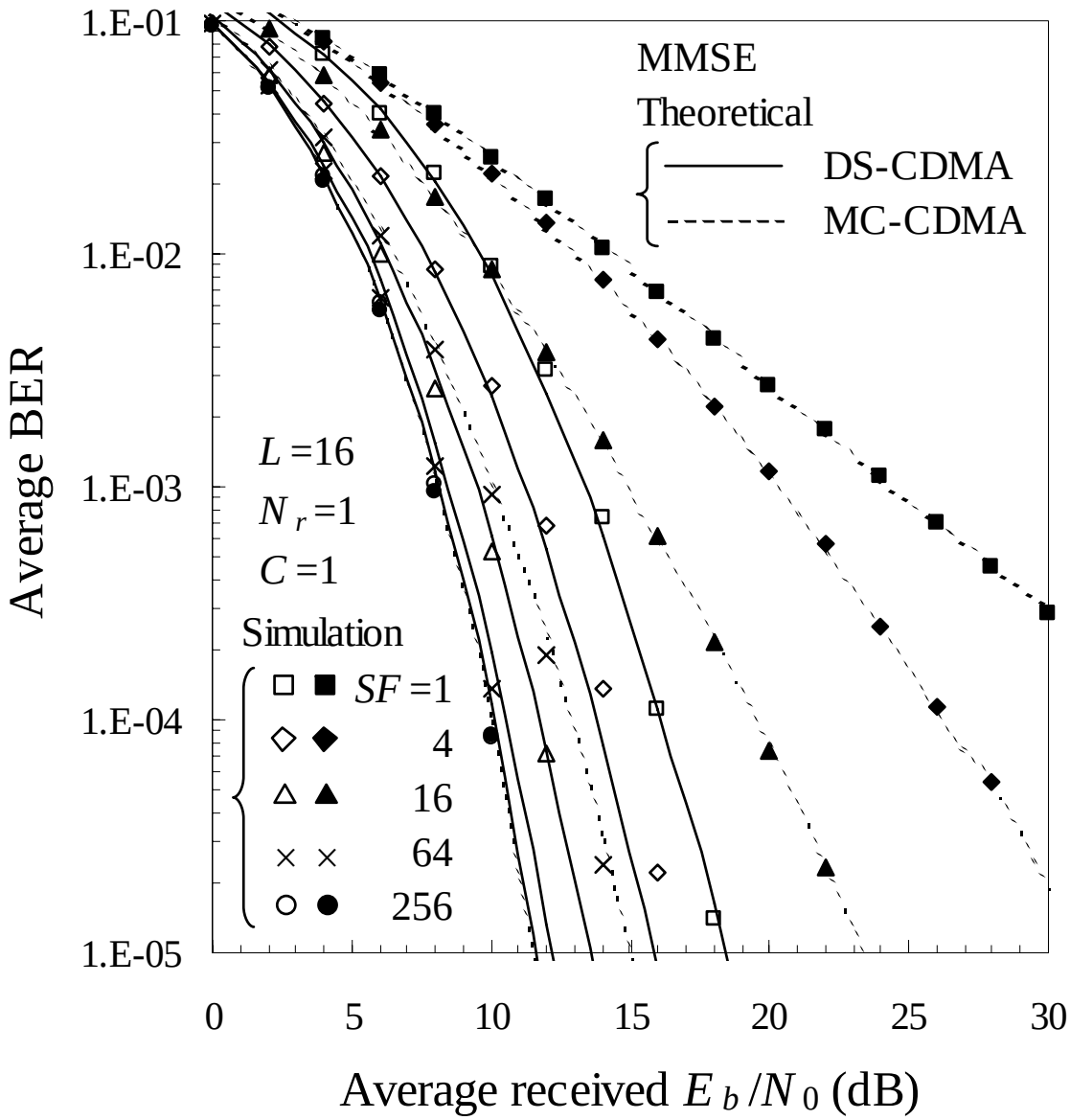
Introduction of FDE to DS-CDMA

- As the spreading factor SF becomes smaller (higher data transmission rate)
  - BER performance degrades with Rake combining
  - On the other hand, BER performance with MMSE-FDE improves and produces no BER floor
- Complexity of MMSE-FDE does not depends on the no. of paths *L* while that of Rake grows as *L*



DS with FDE vs. MC with FDE

- Single user case (C=1)
- DS-CDMA is better than MC-CDMA since it can benefit from a larger frequency-diversity effect

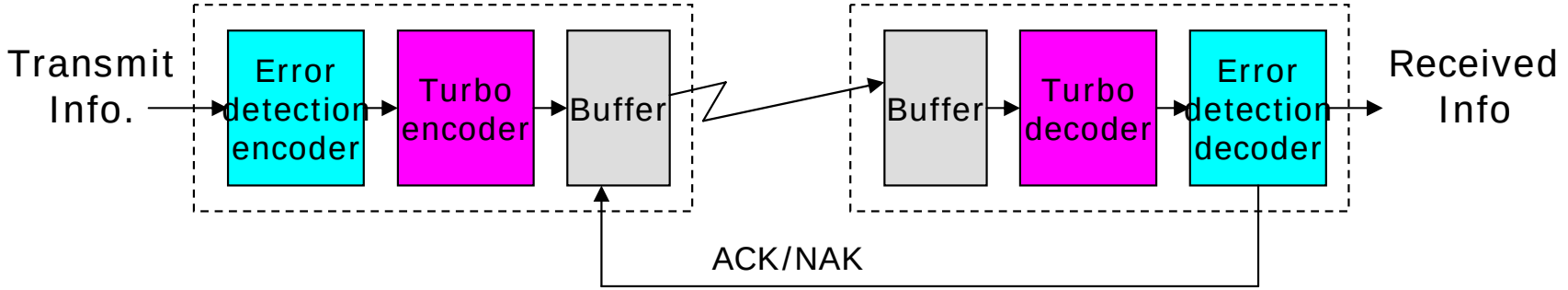


High-speed Packet Access

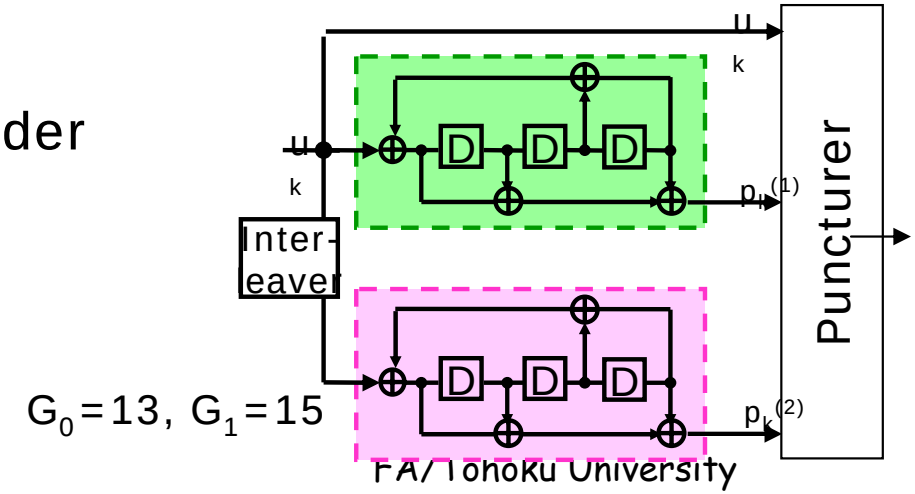
- D. Garg and F. Adachi, “DS- CDMA with Frequency-Domain Equalization for High Speed Downlink Packet Access,” Proc. 60th IEEE Vehicular Technology Conference (VTC), Los Angeles, CA, 26-29 Sept, 2004.
- D. Garg and F. Adachi, “Application of rate compatible punctured turbo coded hybrid ARQ to MC-CDMA mobile radio,” ETRI Journal, Vol. 26, No. 5, pp. 405-412, Oct. 2004.
- D. Garg and F. Adachi, “Throughput comparison of turbo-coded HARQ in OFDM, MC-CDMA and DS-CDMA with frequency-domain equalization,” IEICE Trans. Commun., Vol.E88-B, No.2, pp.664-677, Feb. 2005.

Hybrid ARQ (HARQ)

- Packet services will dominate in 4G. Promising error control is HARQ combined with CDMA with FDE
- For packet transmission, some form of error control is necessary
- Hybrid automatic repeat request (HARQ) with turbo coding seems to be a promising error control scheme
- Be it MC- or DS-CDMA, HARQ will be inevitable for error control

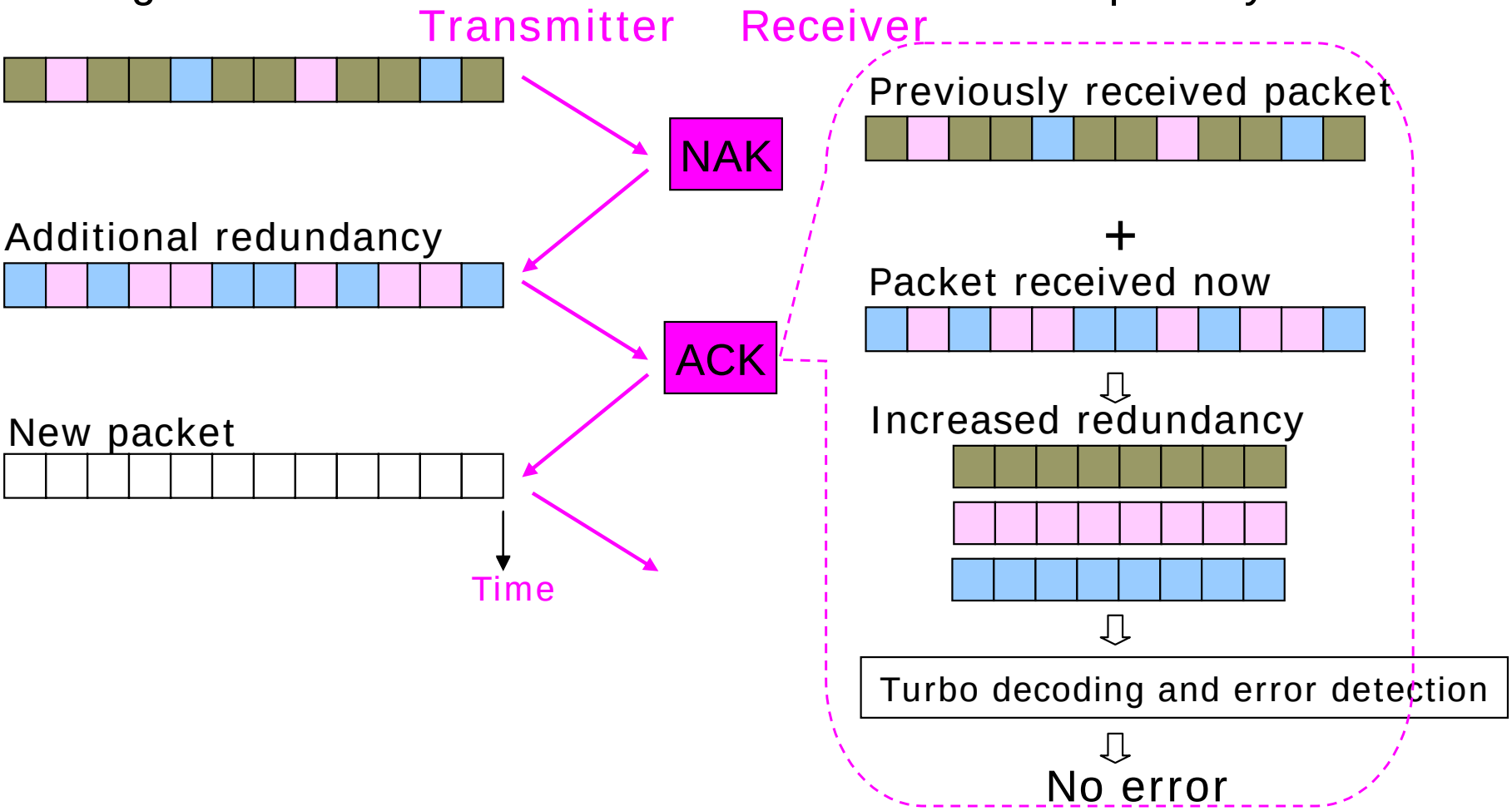


- Turbo encoder



Incremental Redundancy (IR)

- Parity bits are transmitted only when requested
- As the redundancy is increased with each retransmission, the coding rate decreases and the error correction capability is better

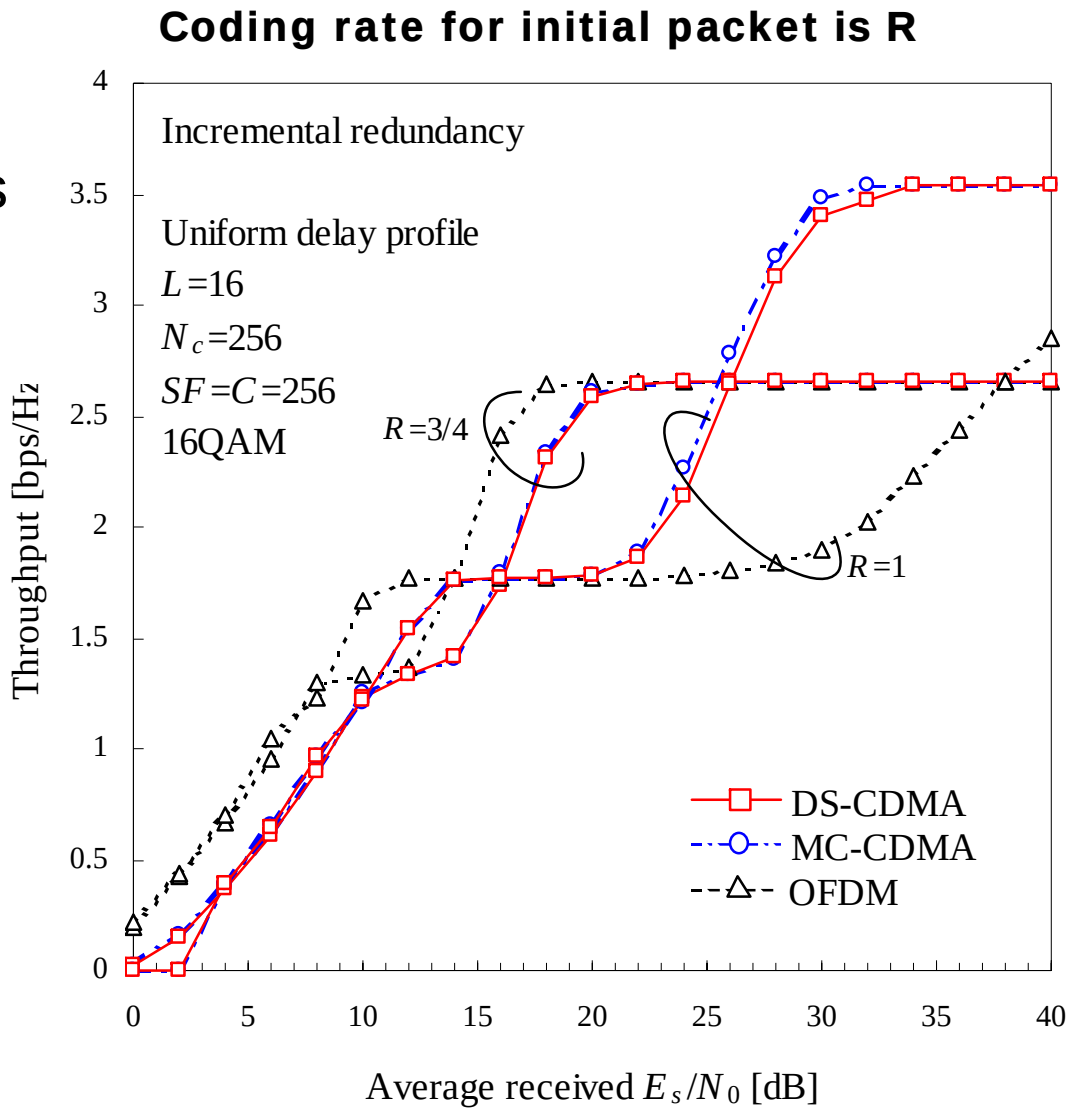


J. Hagenauer, "Rate-compatible punctured convolutional codes (RCPC codes) and their application," IEEE Trans. Commun., vol. 36, pp.389-400, April 1988

DS vs. MC for IR-HARQ

- MC- and DS-CDMA provide better throughput than OFDM in high E_s/N_0 regions
  - Since they avail from frequency diversity gain and retransmission may not be necessary
  - Puncture pattern

R	1	3/4
P_1	$\begin{bmatrix}1&1\\0&0\\0&0\end{bmatrix}$	$\begin{bmatrix}1&1&1&1&1&1\\1&0&0&0&0&0\\0&0&0&1&0&0\end{bmatrix}$
P_2	$\begin{bmatrix}0&0\\1&1\\0&0\end{bmatrix}$	$\begin{bmatrix}0&0&0&0&0&0\\0&1&1&1&1&0\\1&1&0&0&1&1\end{bmatrix}$
P_3	$\begin{bmatrix}0&0\\0&0\\1&1\end{bmatrix}$	



- Initial rate 1: The coding rate after the second transmission is 1/2 and after third transmission is 1/3.
- Initial rate ¾: The coding rate after the second transmission is 3/8 which is very close to 1/3.

Multi-hop Virtual Cellular Network (VCN)

- E. Kudoh and F. Adachi, “Power and Frequency Efficient Wireless Multi-hop Virtual Cellular Concept,” IEICE Trans. Commun., Vol.E88-B, No.4, pp.1613-1621, Apr. 2005.

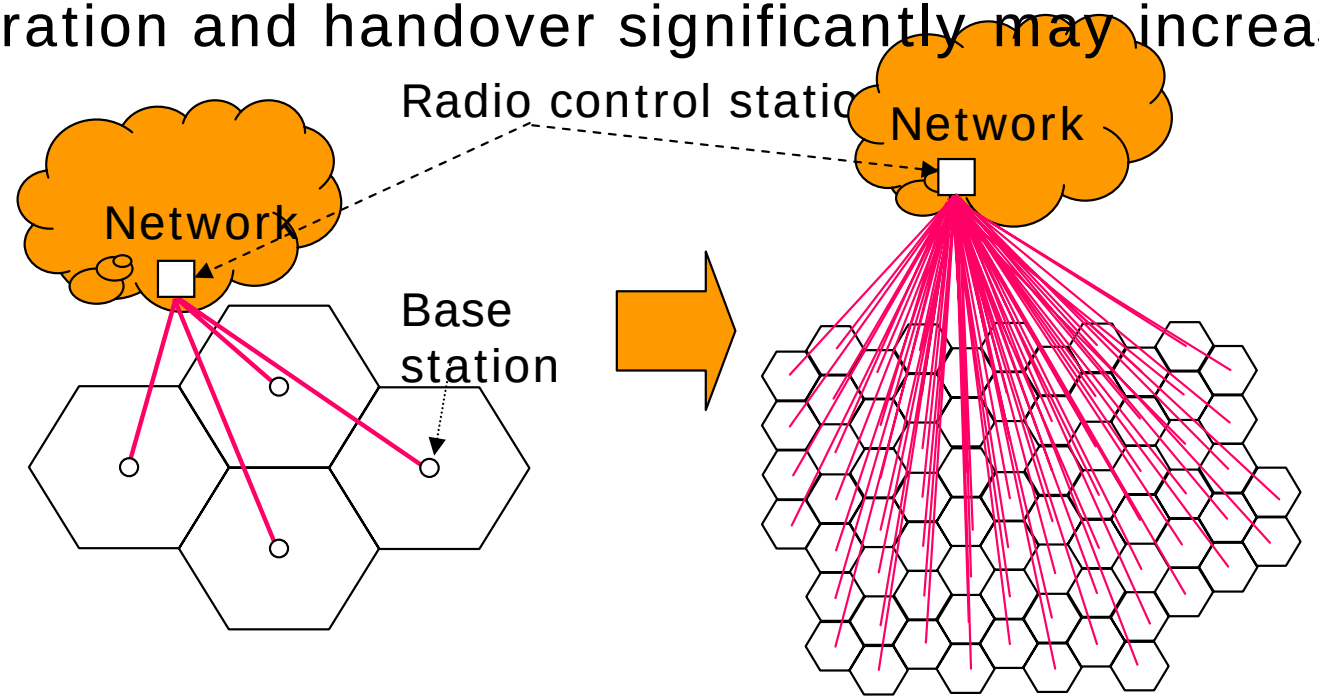
Power Problem

- Links for 100Mbps~1Gbps are severely power-limited
  - Peak power is in proportion to "$f^{2.6}$ x transmission rate [Hata].
  - Peak transmission power for 100Mbps@5GHz is about 135,000 times that of 8kbps@ 2GHz, e.g., 1W --> 135kW. Obviously, this cannot be allowed.
  - Cell size should be reduced by about 29 times (e.g., 1,000m → 34m cell)
- Fundamental change necessary in wireless access network architecture

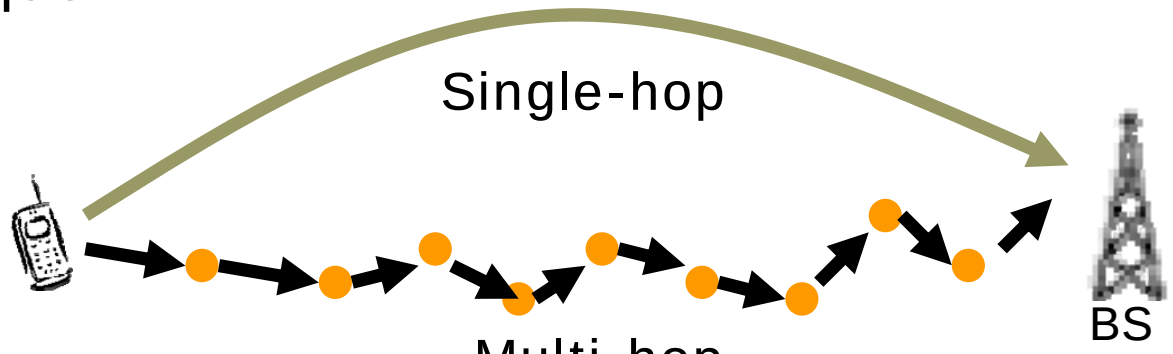
M. Hata, "Empirical formula for propagation loss in land mobile radio services", IEEE Trans. Veh. Technol., VT-29, pp. 317-325, 1980.

Pico-cellular Network

- In nano/pico cellular network, control traffic for location registration and handover significantly may increase

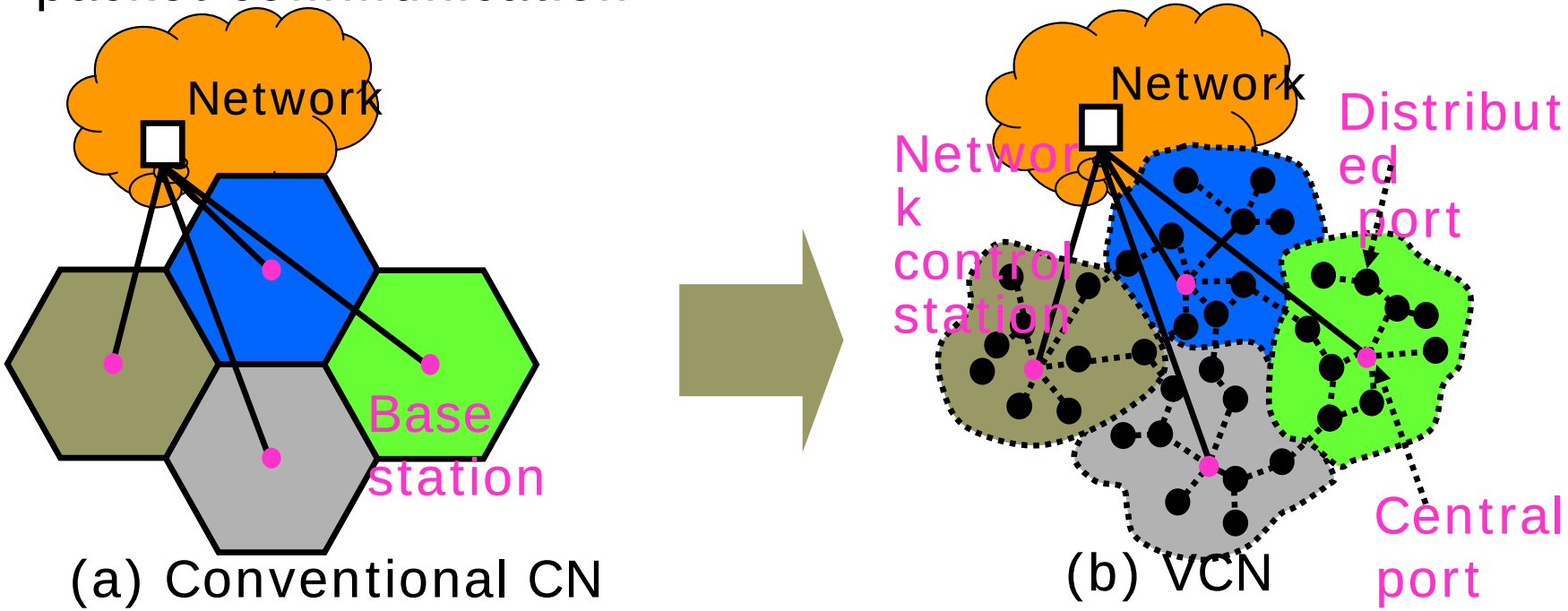


- An efficient solution may be an introduction of multi-hop technique



Multi-hop Virtual Cellular Network (VCN)

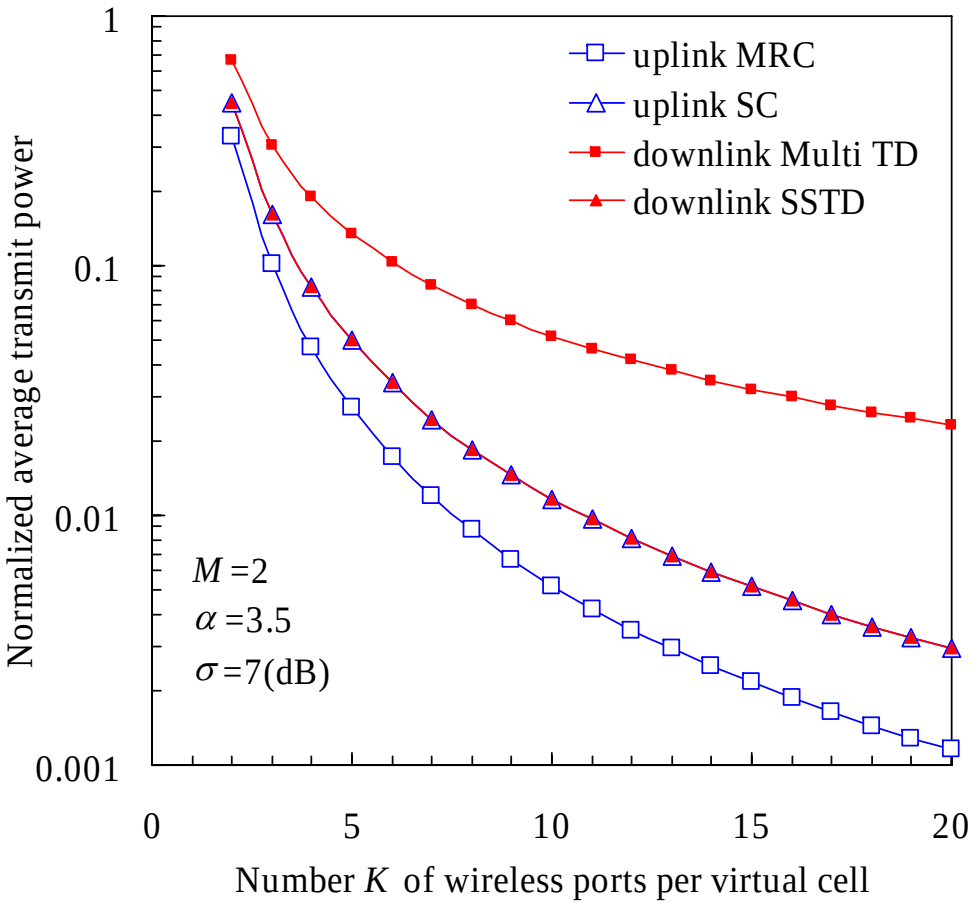
- Virtual cell consisting of many distributed wireless ports
  - One port (central port) acts a gateway to the network
  - Mobile terminal and central port are connected using wireless multi-hop technique
- Virtual cellular network (VCN) is suitable for non-real time packet communication

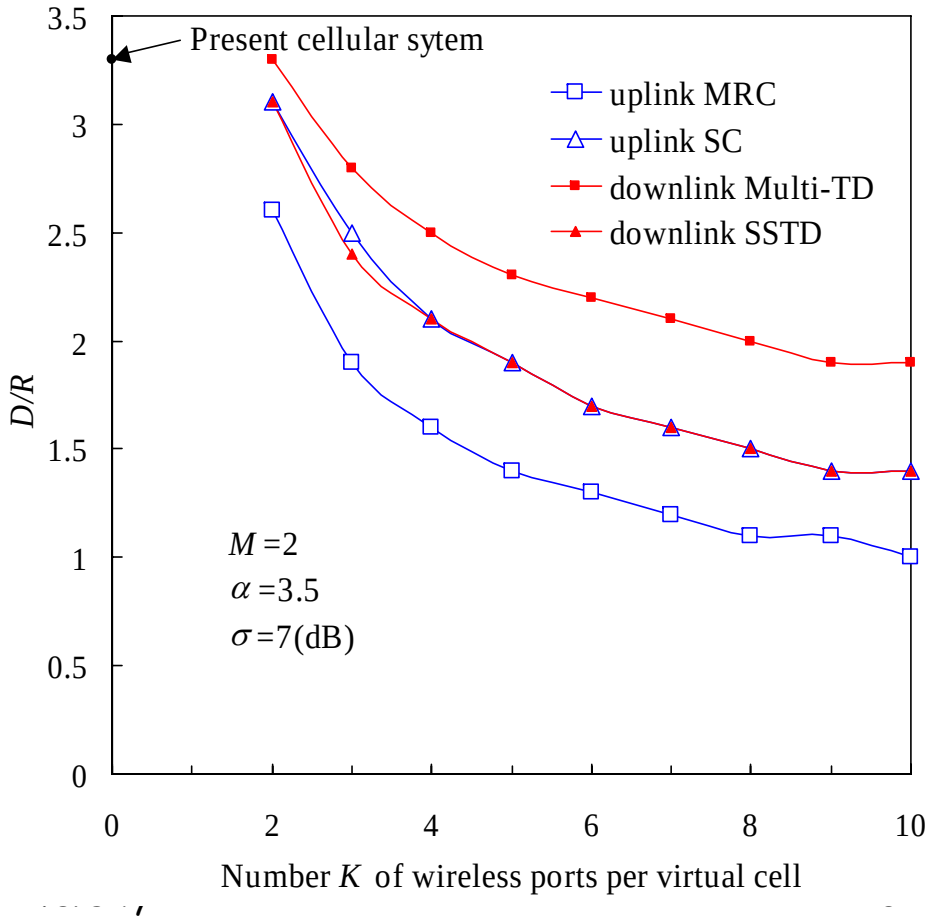


E. Kudoh and F. Adachi, "Power and Frequency Efficient Wireless Multi-hop Virtual Cellular Concept," IEICE Trans. Commun., Vol.E88-B, No.4, pp.1613-1621, Apr. 2005

Power & Frequency Efficiency

- Transmit power of the user link (not the multi-hop links) can be significantly reduced, compared to the present cellular system
- Reducing the transmit power contributes to reducing the frequency reuse distance
  - For D/R<1.7, the same channel can be reused within each virtual cell





Conclusion

- Next generation network is a broadband packet network and requires Giga-bit wireless technology of ~1Gbps capability
- Killer application: Wireless visual communications?
- Frequency-domain equalization technique can improve the transmission performance
  - Either CDMA or OFDM can be used since both can provide similar performance
  - HARQ for improved packet transmissions
- Virtual cellular network (VCN)
  - Use of distributed wireless ports and wireless multi-hop technology can significantly reduce the transmit powers
  - Distributed channel allocation, multi-hop route construction, multi-route coded diversity, distributed antennas, seamless handover, etc.
- Other important techniques
  - Adaptive modulation & coding (AMC)
  - Scheduling & multi-user diversity
  - MIMO, etc.
- There are lots of interesting and important research topics before the born of next generation wireless systems

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