Broadband Wireless Technology for Next Generation Mobile Communications Systems

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OUTLINE

- Wireless Evolution
- Which Multiaccess Technique Should Be Used in 4G??
- A New Approach In Mobile Networks

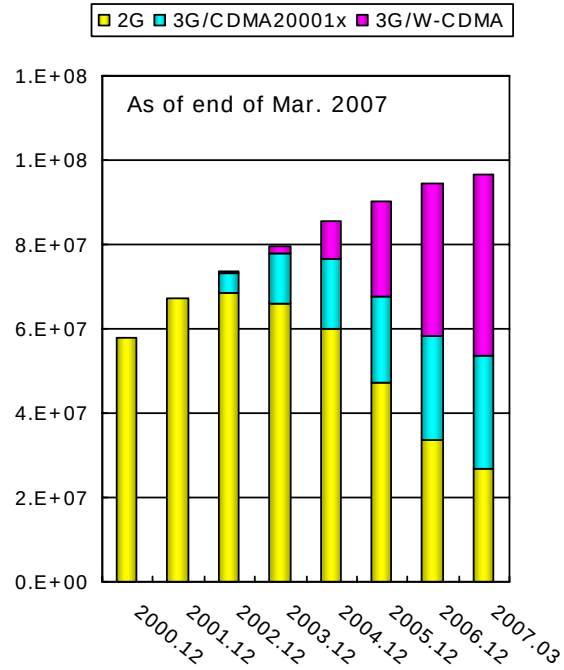
Wireless Evolution

- From 2G to 3G
- Then into 4G

F. Adachi, "Wireless past and future - evolving mobile communications systems," IEICE Trans. Fundamentals, vol. E84-A, pp. 55-60, Jan. 2001.

Shift To 3G Systems Is On Going

- 3G services (~384kbps) started in 2001 in Japan. Growth rate of 3G systems were very slow in the first few years, but now it is really taking off.
- Total No. of Cellular Subscribers
  - 96,717,900
- 2G (26,808,700)
  - PDC: 26,211,500
  - cdmaOne: 597,200
- 3G (69,909,200)
  - 72.3% of total
  - W-CDMA: 43,189,600
  - CDMA2000 1x: 26,719,600



Internet Access

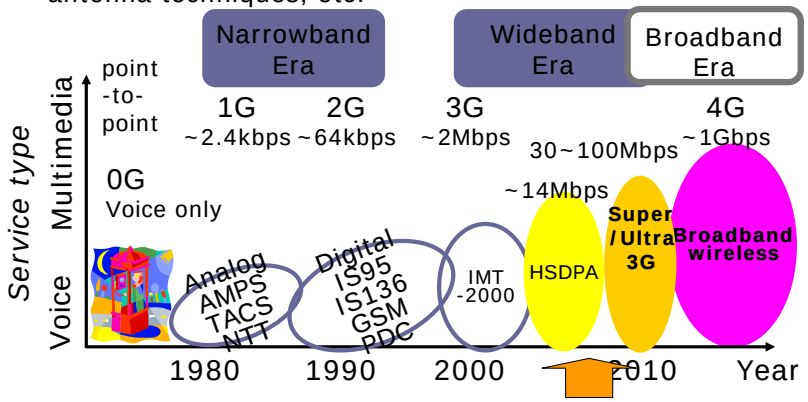
- Towards broadband multimedia services
  - In line with the increasing popularity of Internet in fixed networks, cellular systems are evolving from simply providing traditional voice commun. services to providing broadband multimedia services through Internet access.
- Internet cellphones @end of Mar. 2007 (source: TCA)
  - Total cellular users:
    96,717,900 (penetration 75.7%*)
    Japan population estimate:127.69m @Oct. 2005
  - Users connected to Internet: 83,407,900 (86.2%)
    - i-mode: 47,290,900
    - Ezweb: 22,981,500
    - Yahoo Ke-tai: 13,135,500

3.5G and 3.9G Systems

- 3G systems will continue to evolve to meet the demands broadband wireless services (internet related) and substantially strengthen its downlink data rate capability.
  - High-speed downlink packet access (HSDPA), called 3.5G systems of ~14Mbps/5MHz started in 2006.
- Even ~14Mbps data rate capability of 3.5G will sooner or later become insufficient.
- Before 4G, a 3.9G close to 4G will appear to provide broadband services of 50~100Mbps/20MHz using the 3G bands.

Evolution into 4G

- In 4G systems, a peak data rate of 1Gbps is dmanded
  - Perhaps, an available radio bandwidth may be limited to 100MHz.→ some advanced wireless techniques to achieve more than 10bps/Hz are necessary.
  - E.g., Powerful error control, multi-input/multi-output (MIMO) antenna techniques, etc.

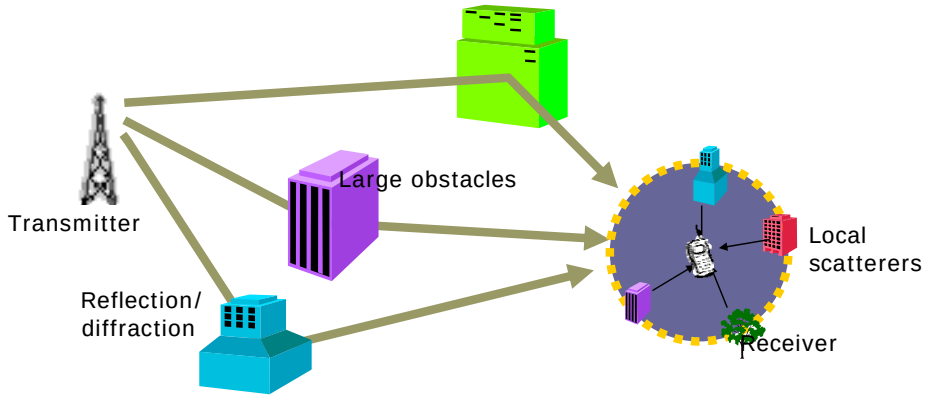


Broadband Channel

- To correctly understand the signal transmission in a mobile communications system, it is important to know the radio wave propagation at first.

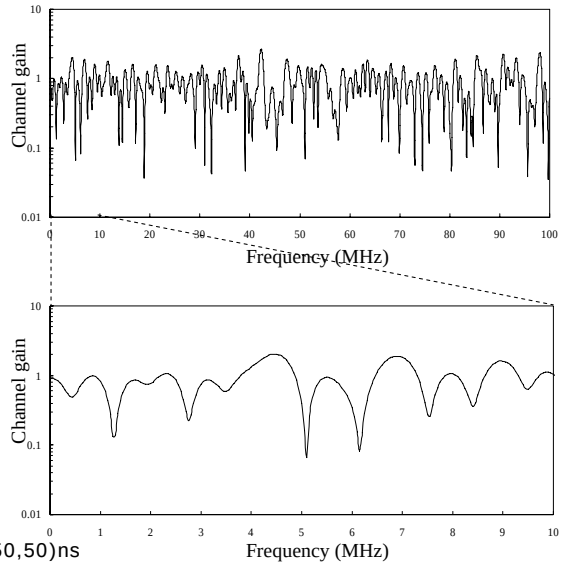
Wireless Propagation Channel Model

- In terrestrial wireless communications, the transmitted signal is reflected or diffracted by large buildings between transmitter and receiver, creating propagation paths having different time delays.



Frequency Selective Channel

- With broadband modulation, the transfer function of wireless channel is not constant and varies over the signal bandwidth.
- Challenge is to transmit data at high speed (close to 1 Gbps) with high quality over such a severe frequency-selective channel.



L=16
Uniform power delay profile
l-th path time delay=100/ + [-50,50)ns

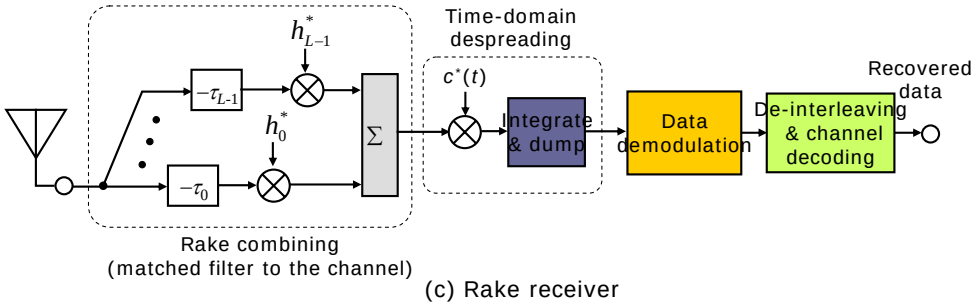
Which Multiaccess Technique Should Be Used in 4G?

- In 3G systems, DS-CDMA is adopted since it is a very flexible multiaccess technique.
- Which will be an optimal wireless access in a severe frequency-selective channel, single-carrier CDMA or multicarrier 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

Rake Receiver

- Present 3G systems use rake combining, which is a channel matched filter.
- Rake combining can improve the BER performance if the channel frequency-selectivity is not too strong (or the number L of resolvable paths is not too large).

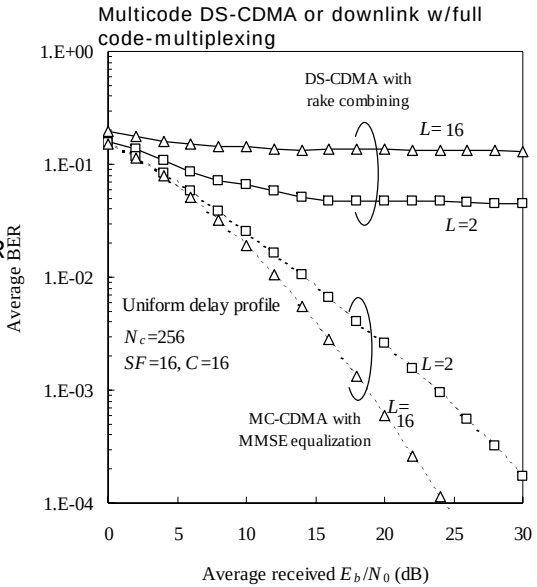


(c) Rake receiver

F. Adachi, M. Sawahashi and H. Suda, "Wideband DS-CDMA for next generation mobile communications systems," IEEE Commun. Mag., vol. 36, pp. 56-69, Sept. 1998.

DS with Rake vs. MC with FDE

- As the number of resolvable paths increases, the achievable BER performance of DS-CDMA with rake combining significantly degrades due to strong IPI.
  - Even with L=2, a high BER floor appears resulting from ICI if the code-multiplexing order is high.
- On the other hand, MC-CDMA with MMSE-FDE provides much better performance.
  - Performance improves as L increases.

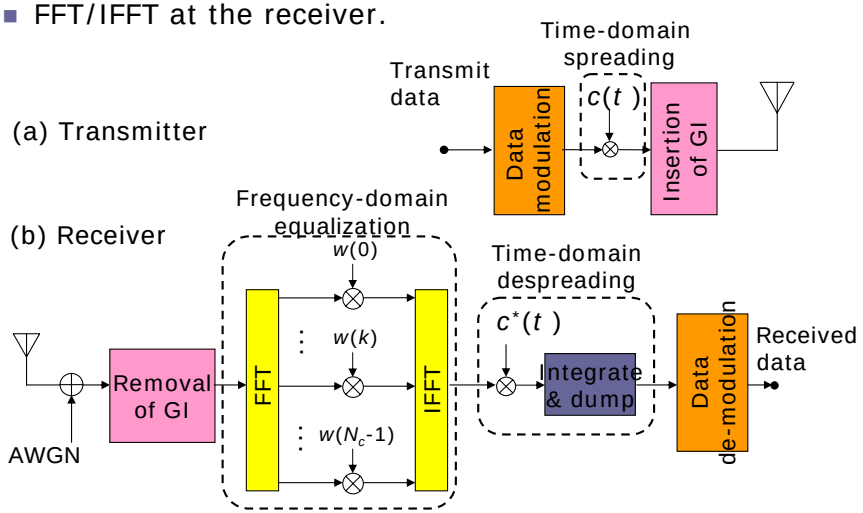


Application of Frequency-domain Equalization (FDE) to DS-CDMA

- One-tap FDE can replace rake combining to have much improved performance.

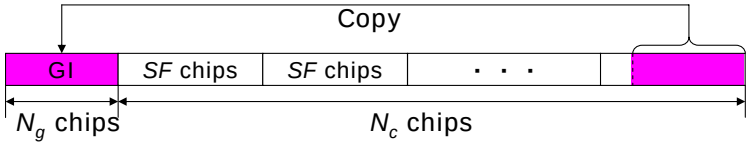
- F. Adachi, D. Garg, S. Takaoka, and K. Takeda, "Broadband CDMA techniques," IEEE Wireless Commun. Mag., Vol. 12, No. 2, pp. 8-18, April 2005

- Rake combining is replaced by one-tap FDE.
  - Insertion of guard interval (GI) at the transmitter.
  - FFT/IFFT at the receiver.



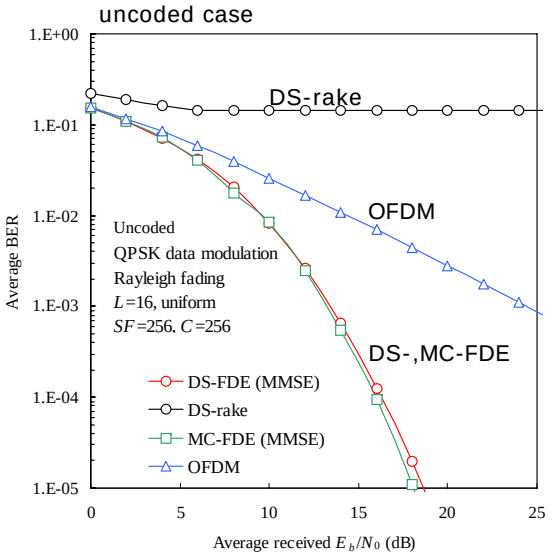
Chip Block Structure of DS-CDMA

- Cyclic prefix is inserted into the guard interval (GI) for FDE.



Performance Comparison

- FDE can achieve
  - significantly better performance than rake receiver.
  - better BER performance than OFDM even for full multiplexing (no. of users, C, is equal to SF=256).



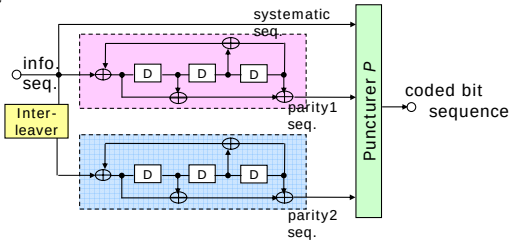
Channel Coding

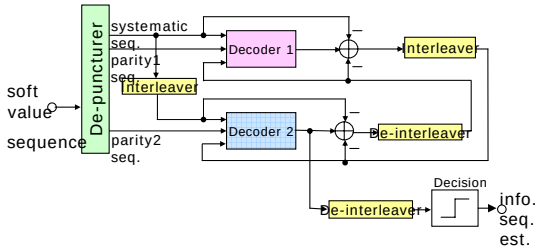
- Channel coding is an indispensable technique to improve the transmission performance in a fading channel.
- Turbo coding is powerful and improves the BER performances of DS- and MC-CDMA.
- Turbo coding is used in 3G systems using DS-CDMA.

- D. Garg and F. Adachi, "Performance comparison of turbo-coded DS-CDMA and MC-CDMA with frequency domain equalization and higher level modulation," Proc. IEEE VTC'04-Fall, Los Angeles, USA, Sept. 2004.

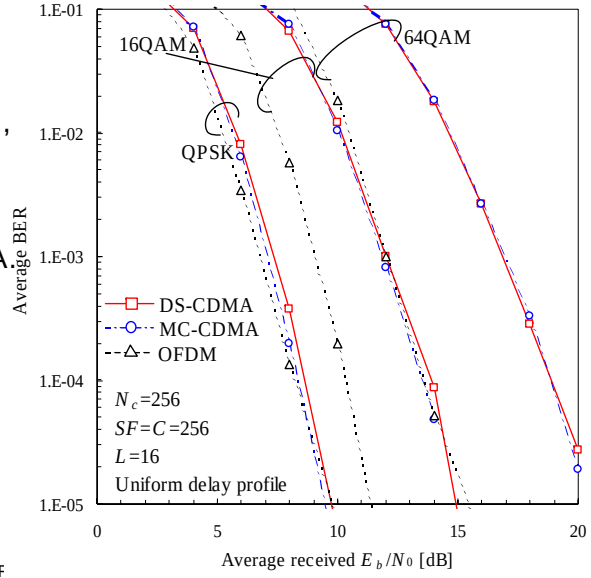
Turbo Coding

- Encoder consists of recursive systematic convolutional (RSC) component encoders connected in parallel with interleaver between them.
  - Eg. Encoder with a constraint length 4 and (13, 15) RSC component encoders
- Decoder is an iterative decoder that exchanges information among the component decoders.





- MC- and DS-CDMA performances coincide for all the modulation levels.
- For 16QAM and 64QAM, however, OFDM provides a better BER performance than either MC- or DS-CDMA.



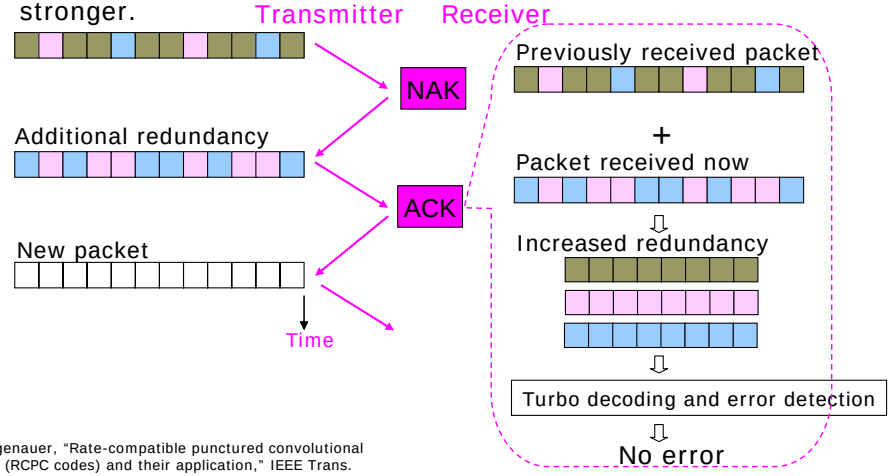
High-speed Packet Access

- Packet services will dominate in 4G systems. For packet transmissions, some form of error control is necessary to satisfy the quality requirement.
- Hybrid ARQ w/incremental redundancy (IR) strategy is a promising technique.

- 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.
- D. Garg and F. Adachi, "Packet Access using DS-CDMA with frequency-domain equalization," IEEE Journal of Select. Areas in Commun., Vol. 24, No. 1, pp. 161-170, Jan. 2006.

HARQ with IR Strategy

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

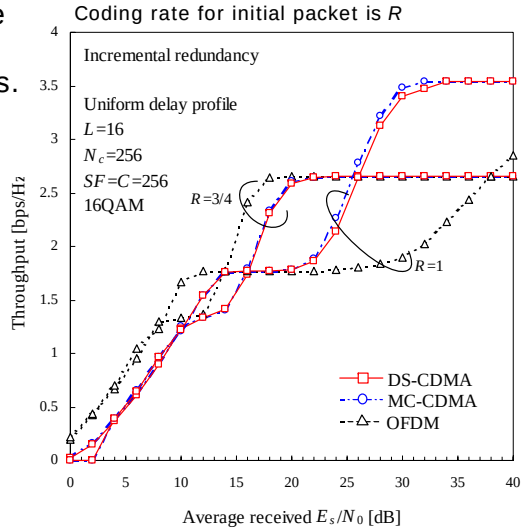


J. Hagenauer, "Rate-compatible punctured convolutional codes (RCPC codes) and their application," IEEE Trans. Commun., vol. 36, pp.389-400, April 1988.

DS vs. MC for HARQ w/ IR

- 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.

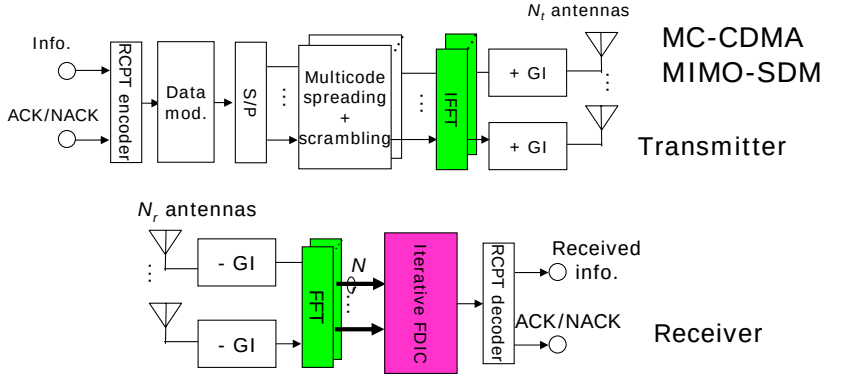
Frequency-Domain MIMO SDM

- Very high speed packet data transmission close to 1GTbps is demanded in 4G. However, an available bandwidth is limited.
- MIMO space division multiplexing (SDM) is a promising technique to increase the data rate with a limited frequency band.

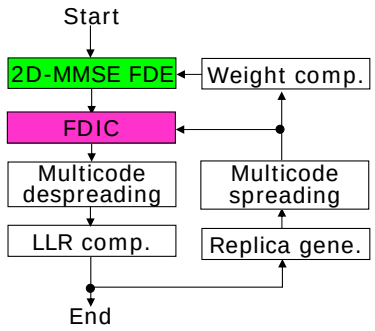
- A. Nakajima, D. Garg and F. Adachi, "Frequency-domain iterative parallel interference cancellation for multicode DS-CDMA-MIMO multiplexing," Proc. IEEE VTC'05 Fall, Vol.1, pp. 73-77, Dallas, U.S.A., 26-28 Sept. 2005.
- A. Nakajima and F. Adachi, "Iterative FDIC using 2D-MMSE FDE for turbo-coded HARQ in SC-MIMO multiplexing," IEICE Trans. Commun. Vol. E90-B, No.3, pp.693-695, Mar. 2007.

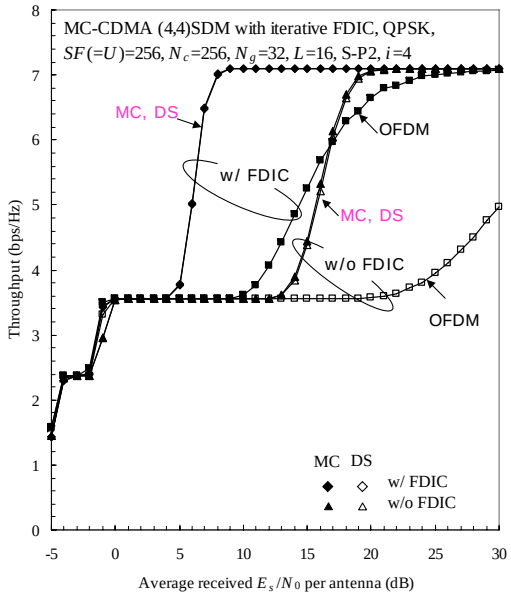
Frequency-Domain SDM

- Joint MMSE frequency-domain equalization (FDE) and parallel interference cancellation (PIC) is repeated for demultiplexing while achieving frequency-diversity gain.



- Iterative FDIC





A New Approach In Mobile Networks

- Another important technical issue for the realization of high data rate 4G mobile networks is the significant reduction of the transmit power from a mobile terminal (MT).

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.

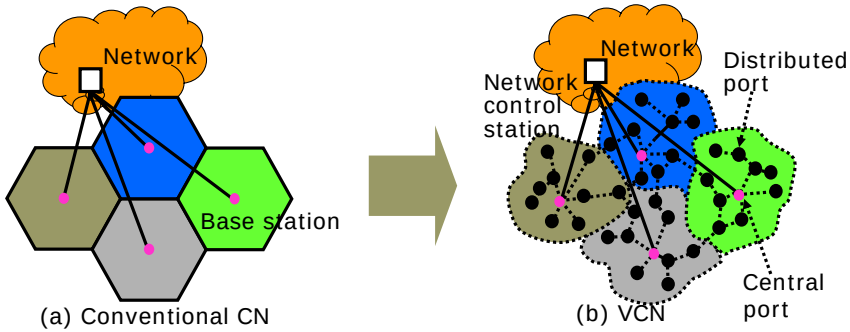
Power Problem

- 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)
  - This seems to be impractical.
- 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.

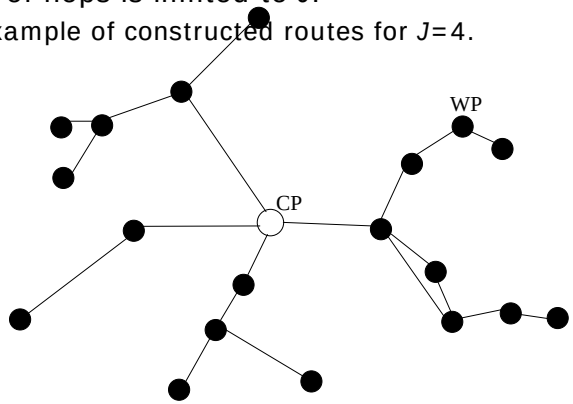
Multi-hop Virtual Cellular Network (VCN)

- Virtual cellular network (VCN) is suitable for non-real time packet communication.
- 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.



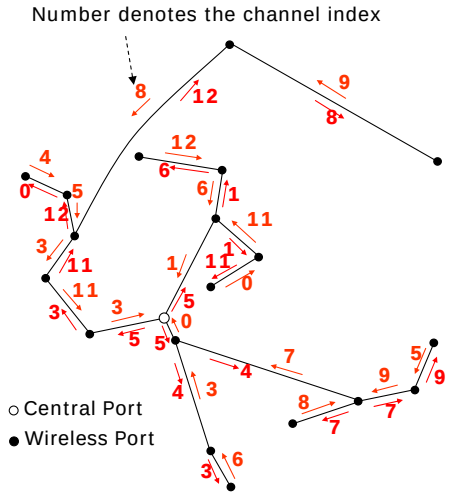
Multih-hop Route Construction

- Multi-hop routes connecting each end wireless port (WP) and central port (CP) are constructed based on the total transmit power minimization criterion.
  - The interference to other multi-hop routes can be minimized.
- To avoid excessive transmission delay, the maximum number of hops is limited to *J*.
  - An example of constructed routes for *J*=4.



Dynamic Channel Allocation

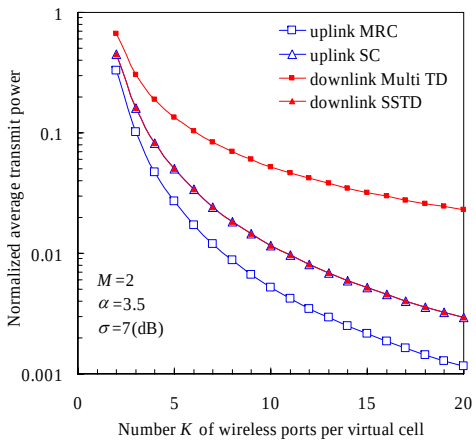
- Channel allocation is an important technical issue to efficiently reuse the limited channel resources.
- In VCN, a distributed dynamic channel allocation (DCA) will be a solution.
- Channel segregation DCA (CS-DCA) is promising
  - Each WP learns about its favorite channels in a distributed manner without requiring any propagation channel information in advance.

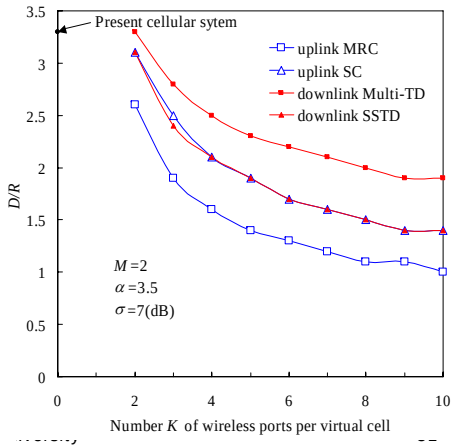


Y. Furuya and Y. Akaiwa, "Channel segregation, a distributed adaptive channel allocation scheme for mobile communication systems", IEICE Trans., Vol.E74, no.6, pp.1531-1537, June 1991.

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

- 4G systems are a broadband packet network and requires Giga-bit wireless technology of ~1Gbps capability.
- Wireless multiaccess technique
  - Frequency-domain signal processing is an important technique to achieve the goal.
  - Either DS- or MC-CDMA with FDE can be used since both can provide similar performance.
  - Frequency-domain HARQ and MIMO can be used to take advantage of the channel frequency-selectivity.
- Network issue
  - Power problem is an important technical issue in 4G network. Some fundamental change needs to be introduced to the wireless network.
  - E.g., multi-hop virtual cellular network, collaborative network, etc.