Perspective of Mobile Communications

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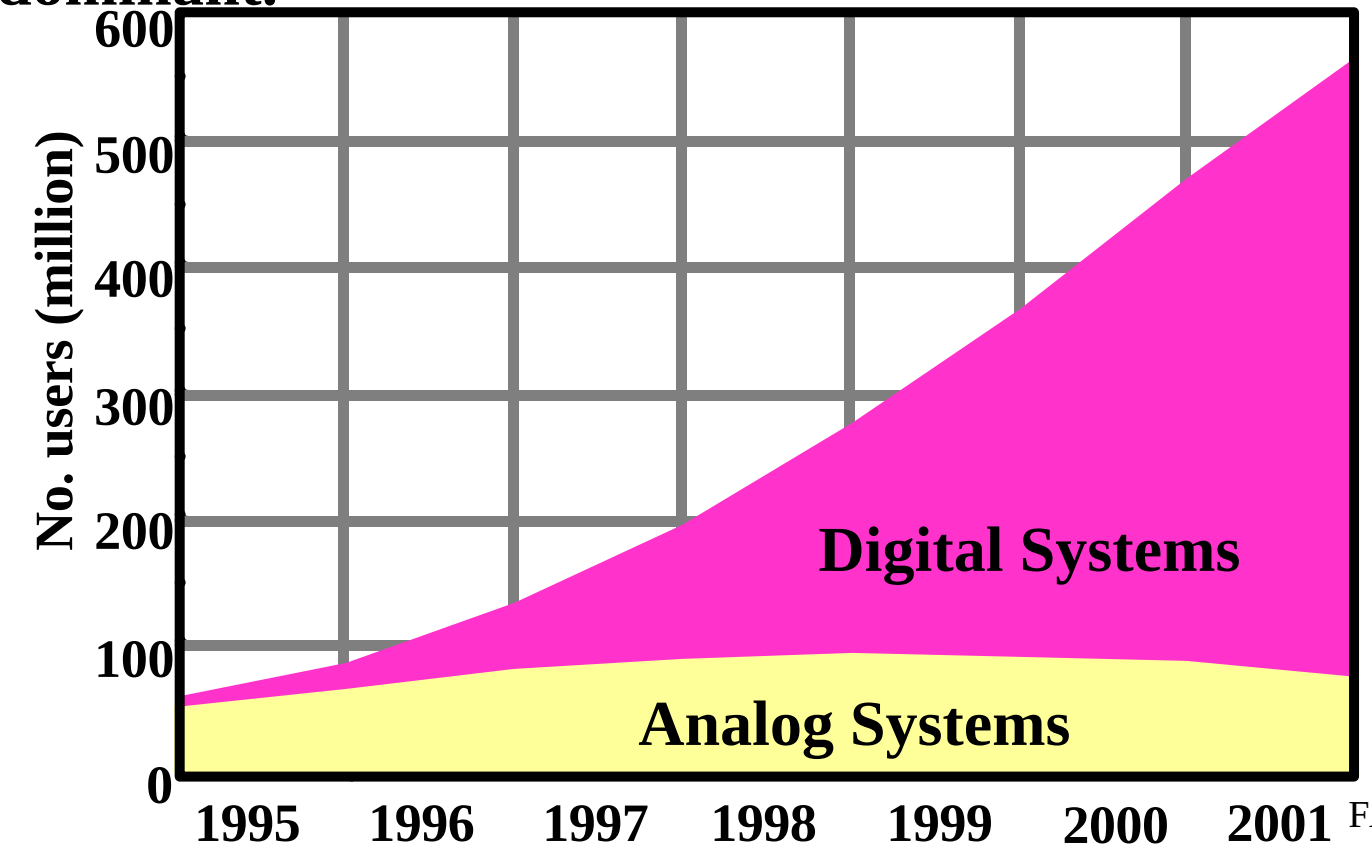
Rapidly Growing Mobile Communications Markets

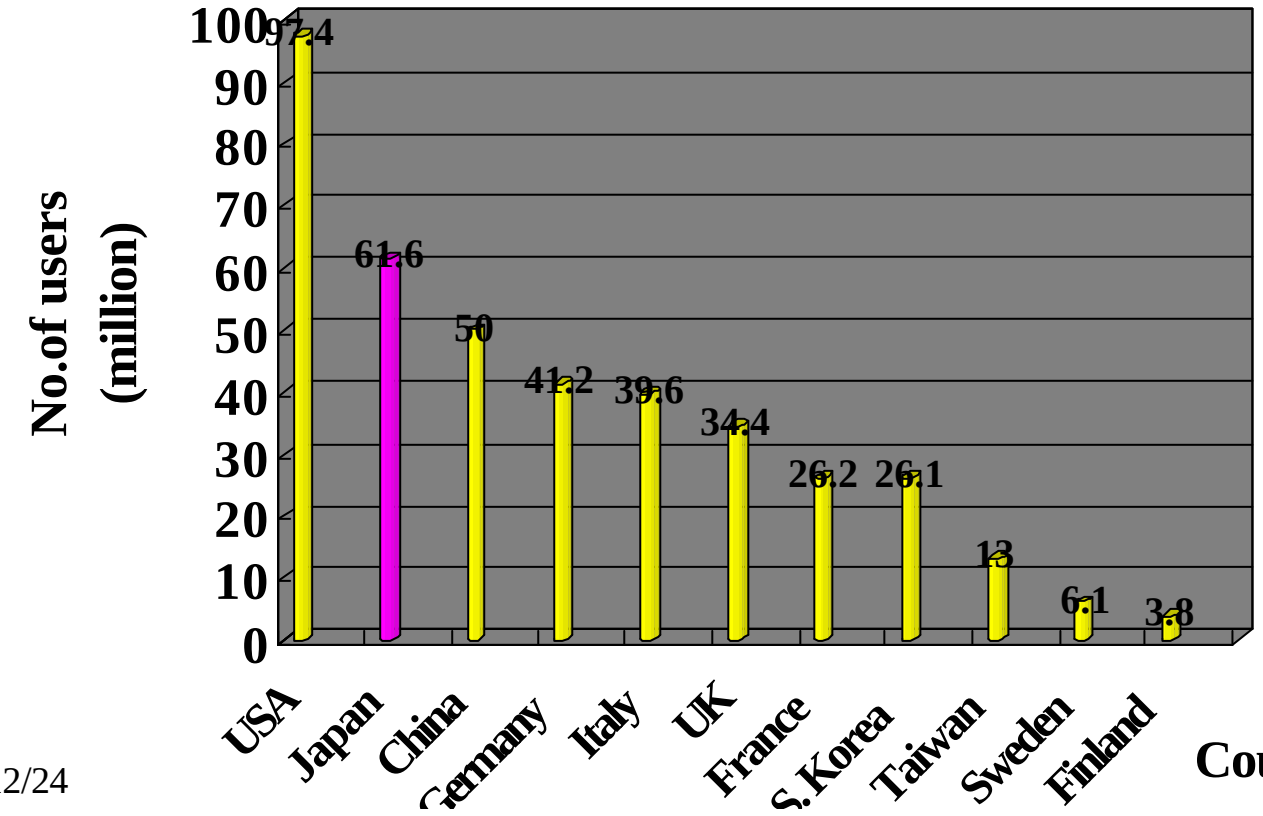
Rapidly Growing Mobile Market

- Total no. of users of Japan, USA and European countries is over 378M.
- Analog systems fade and digital systems become dominant.



Number of Subscriber by country

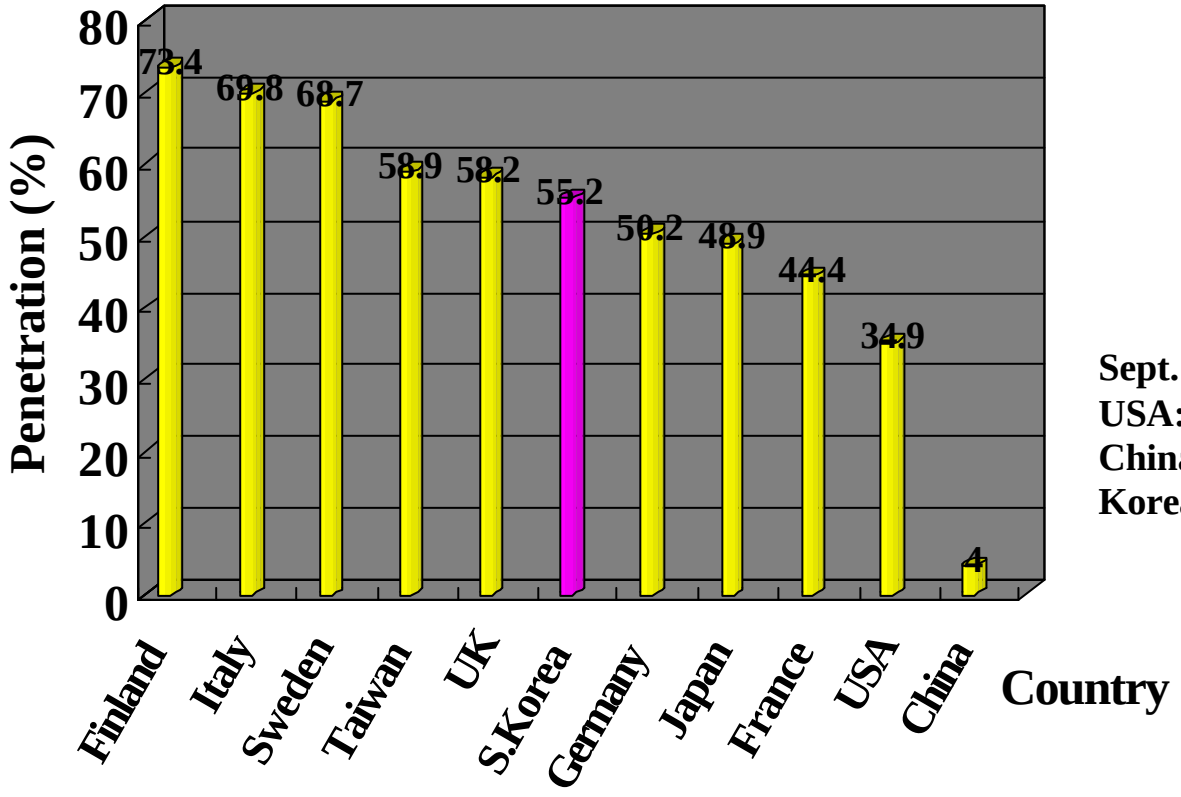
- **USA is No.1 and Japan is second, but China is growing fast and now around 60millions.**
- **Japan markets is growing 0.811M per month.**



Sept. 2000
USA:June 2000
China, Taiwan, S. Korea:Mar.2000

Penetration by Country

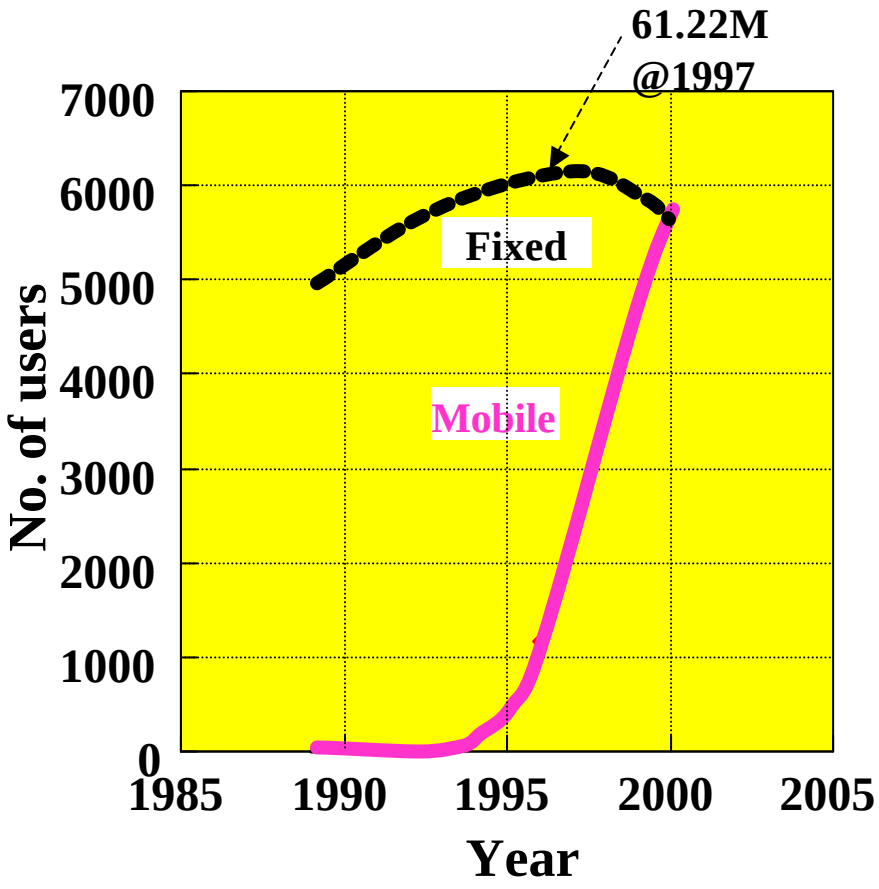
- **Finland has the largest penetration of 73.4%.**
- **Penetration of Japan is 47% and there is still rooms to grow. This will be supported by data users.**



Sept. 2000
USA:June 2000
China, Taiwan, S. Korea:Mar.2000

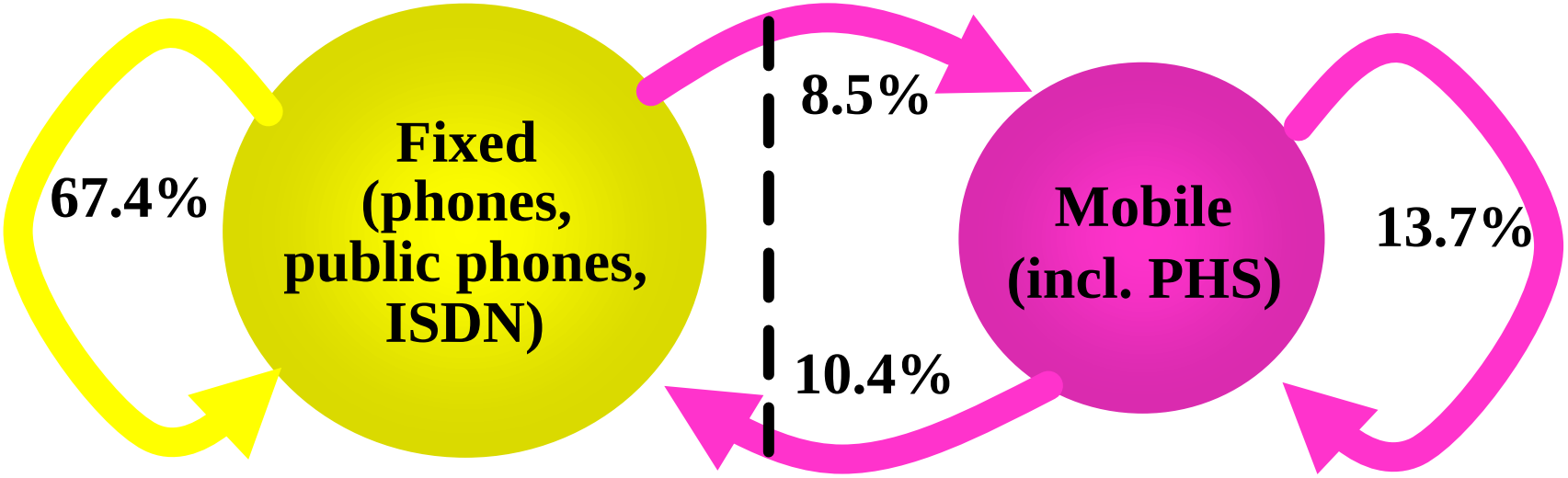
Mobile Networks Will Replace Conventional Fixed Networks Role

- No. of mobile wireless users exceeded that of fixed telephone circuits in March 2000:
  - Cellular: 51.141M
  - PHS: 5.708M
  - Fixed phone : 55.446M
- Mobile wireless traffic is expected to surpass fixed phone traffic in 2001.



Call Flow

- One fixed phone at an office or a home is shared by more than one people. Equivalent no. of users is still higher than that of mobile users.
- Calls to/from mobile users occupy 33% of total calls (123.79calls).

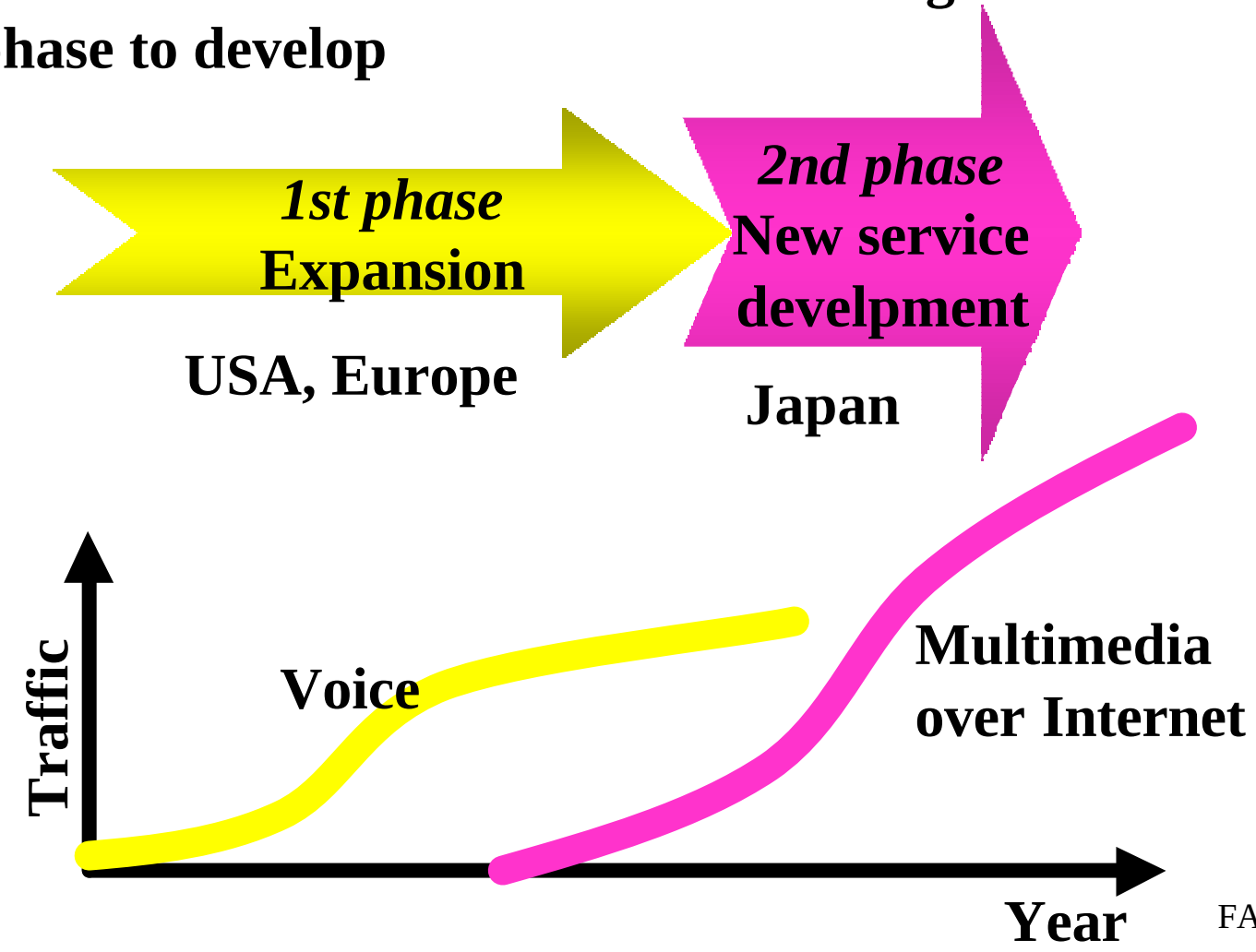


MPT, 1999.3

Mobile Communications Services Are Shifting To Multimedia

- **Communications goal**
  An addition of one more term "any type of information" to the goal, i.e., to communicate any type of information to anyone at anytime from anywhere.
- **Information exchanged via mobile communications systems was firstly, *voice conversation* and now *Internet-related information data*, i.e., e-mail messages, transactions data, entertainment etc., good example is indicated by "i-mode" on PDC.**

- **Mobile commun. Services are entering into a new phase to develop**



Coffee Break

Cellular Concept

Only 20 Years History of Mobile Communications

- **Ultimate goal of communications**

  To communicate *with anyone, at anytime, from anywhere.*

- **Before 1980's**
  - **Public payphones were only available communications tool outside home and offices.**
  - **We should have looked for them when wanted to communicate. This was very inconvenient, particularly for business people. Hard to make a urgent contact with people. Hard to find a pay phone in a suburban area. Long queue in front of a pay phone at a busy place.**
- **After 1980's**
  - **Appearance of mobile communications systems made it possible to contact anyone from outside home and offices when necessary.**
  - **Accepted first in business sectors and now by ordinary people. Penetration rate has been increased to more than 50%.**

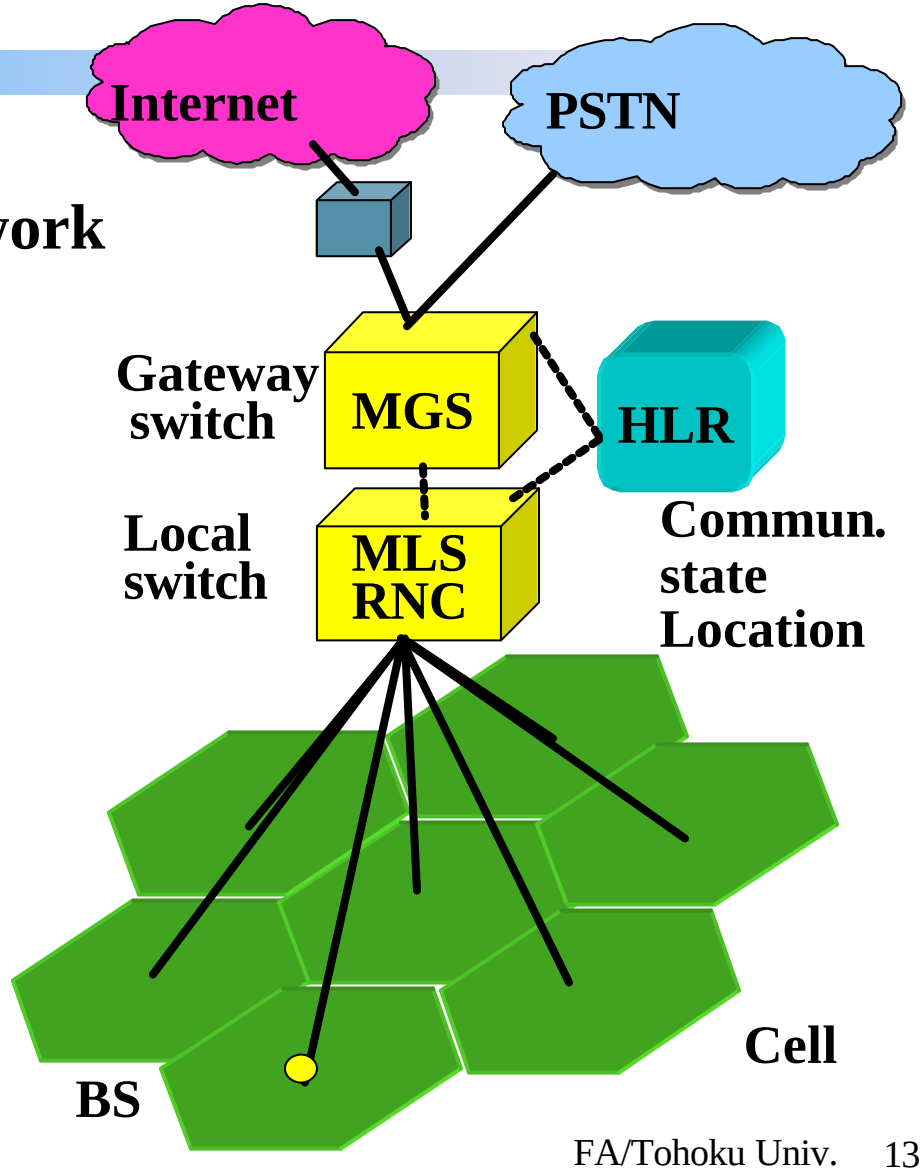
Cellular Concept

- **Birth of cellular concept in 1960's:**
  - **D. Araki, "Fundamental problems of nationwide mobile radio-telephone system", NTT Rev. Elec. Comm. Lab., 1967.**
  - **R. H. Frenkiel, "A high –capacity mobile radiotelephone system …," IEEE Trans. Veh. Tech., 1970.**
- **Wide service area is covered by many base stations, small area covered by each base station is called a cell.**
- **The same carrier frequency is reused at spatially separated different cells. By doing so, limited frequency bandwidths can be efficiently utilized.**

✍ **Transmit powers from mobile terminals can be made small and this led to present portable phones.**

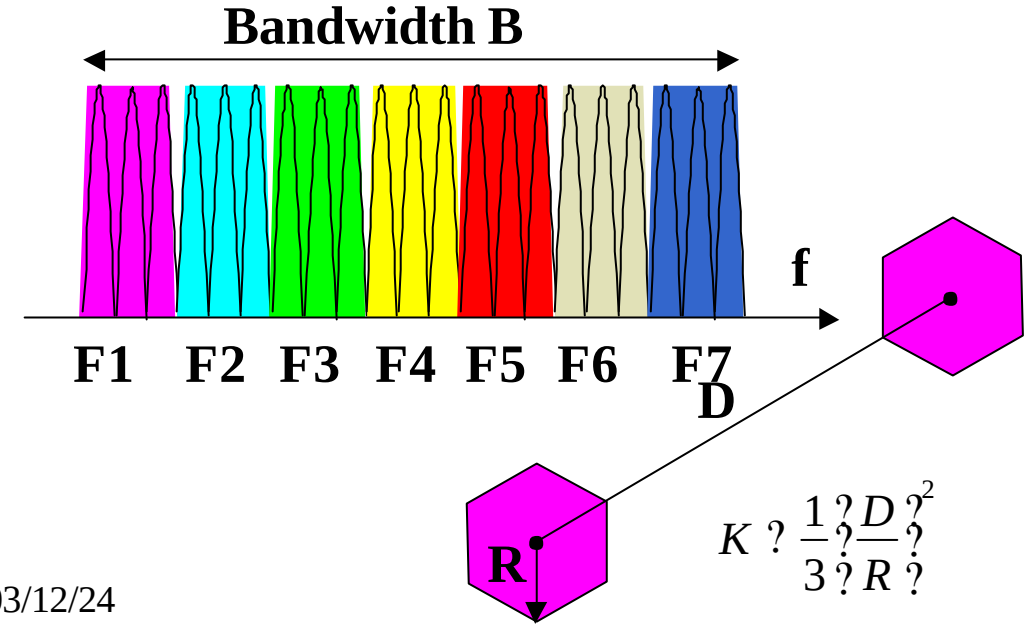
Cellular System

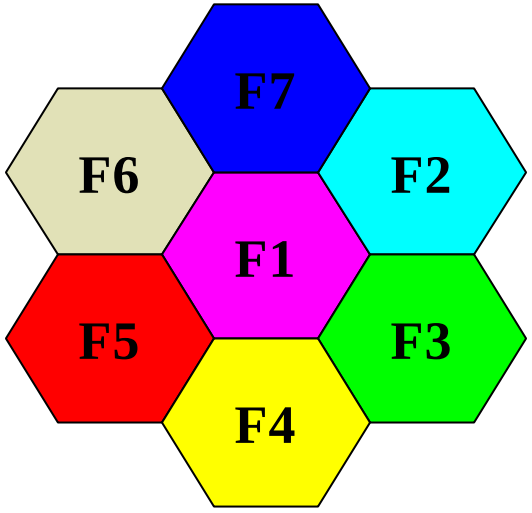
- Core network
  - Electronic switching network
  - No.7 signaling system
  - Home location register (HLR)
- Radio network
  - Radio network controller (RNC)
  - Base station (BS)



Frequency Allocation

- Channels in a given bandwidth are grouped into e.g. seven (K=7) and are allocated to seven base stations.
- How many groups the channels can be grouped into depends on propagation condition and wireless technologies used.



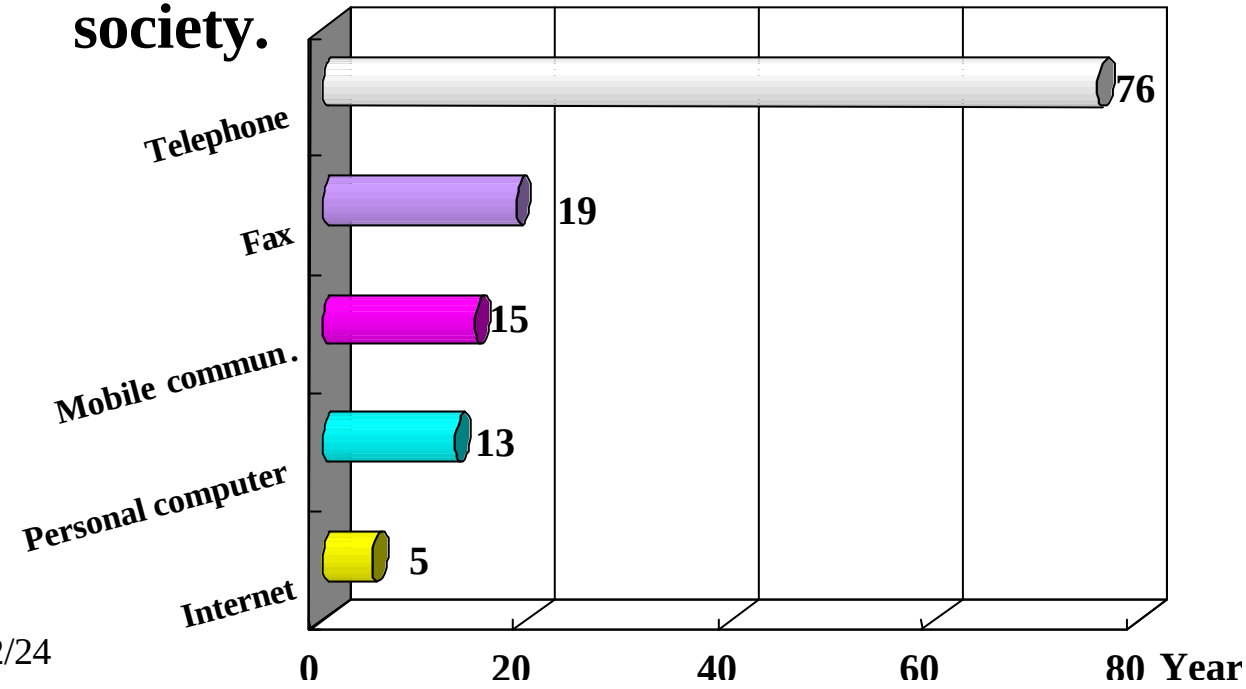


TDMA
Cluster size K=7

Convergence of Mobile Wireless and Internet

Time Taken to Arrive at 10% (House Hold) Point

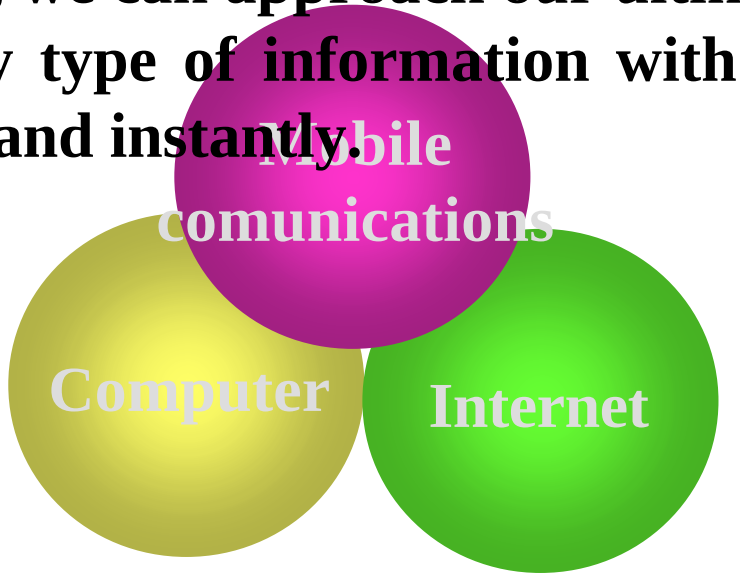
- The rate at which mobile radio and Internet communications services have proliferated throughout our society is striking.
- In the fixed networks, voice conversation was a long-time dominant service, but the introduction of Internet communication services is significantly changing our society.



Source: Communications White Paper, MPT, 1999

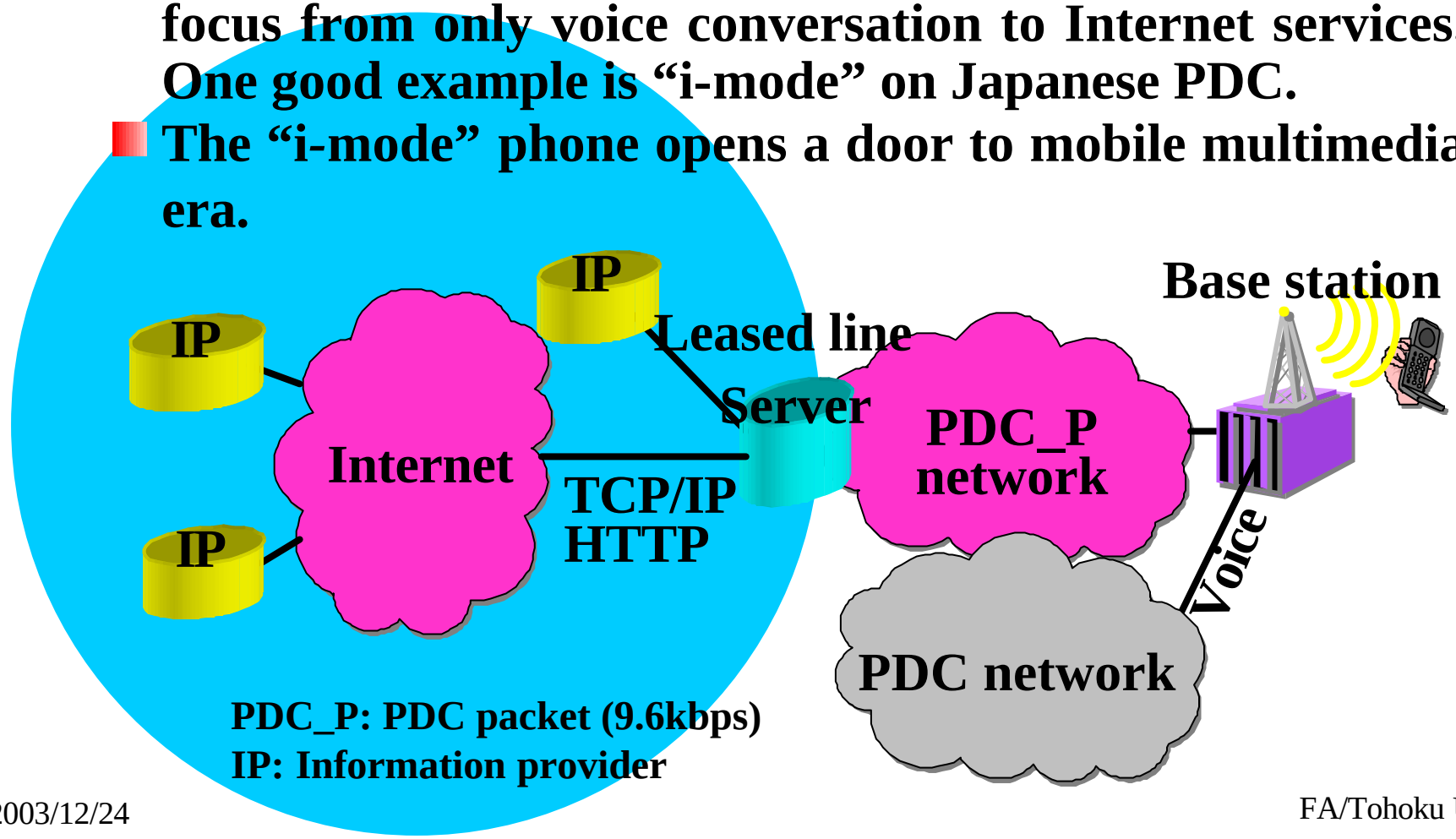
Convergence of Mobile, Inter-net and Computers

- **Mobile phones are becoming not a simple conversation tool but multimedia terminals that can provide a mobile user with functions now available only at offices.**
- **Convergence of *mobile* wireless communications, Internet and computers will drive our society to mobile multimedia society. Mobility is an important factor.**
- **By this convergence, we can approach our ultimate goal: to communicate any type of information with anyone, anytime, anywhere, and instantly.**



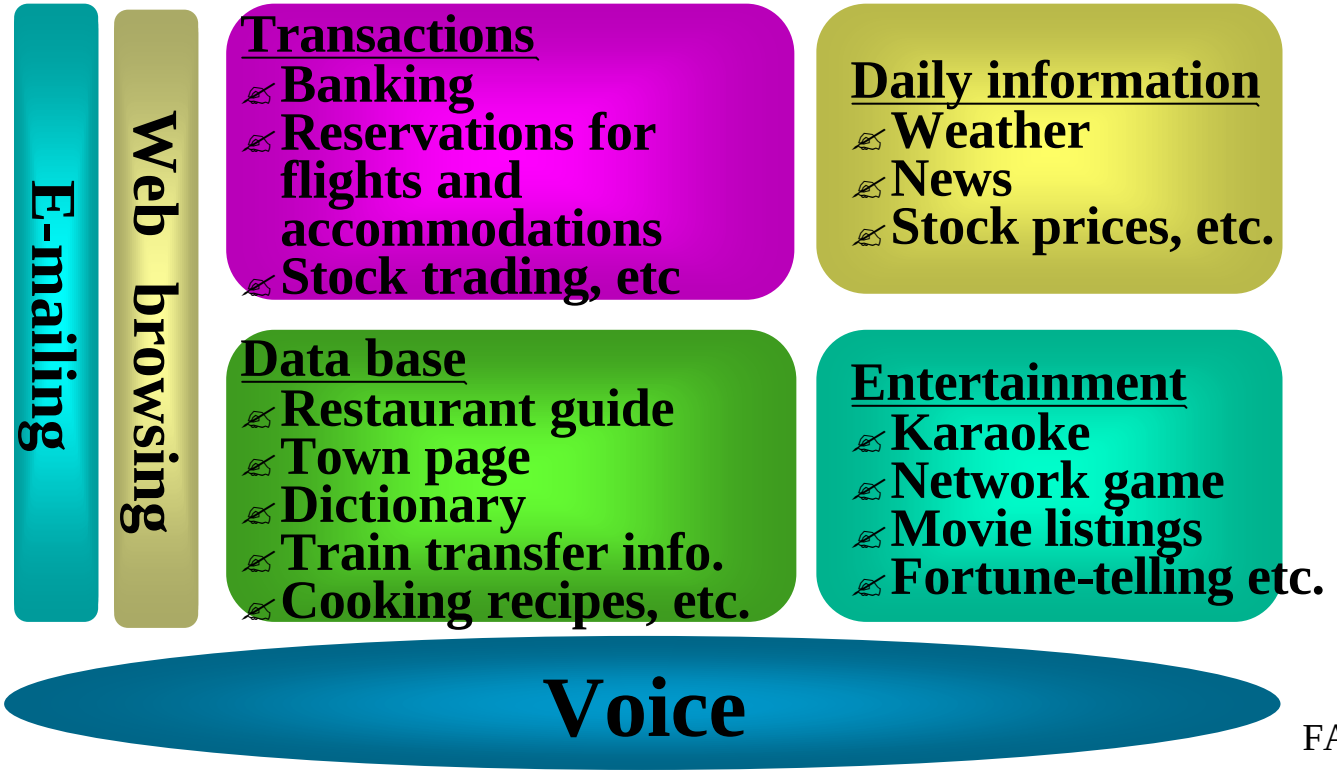
Convergence of Mobile and Internet is Seen in the Success of "*i* mode"

- Mobile communications operators are shifting their focus from only voice conversation to Internet services. One good example is "i-mode" on Japanese PDC.
- The "i-mode" phone opens a door to mobile multimedia era.



“i-mode” Creates Mobile Multimedia Era

- **A variety of services via Internet.**
- **Key success of “i-mode” services is an addition of Internet services *on top of basic services* (voice comunications).**

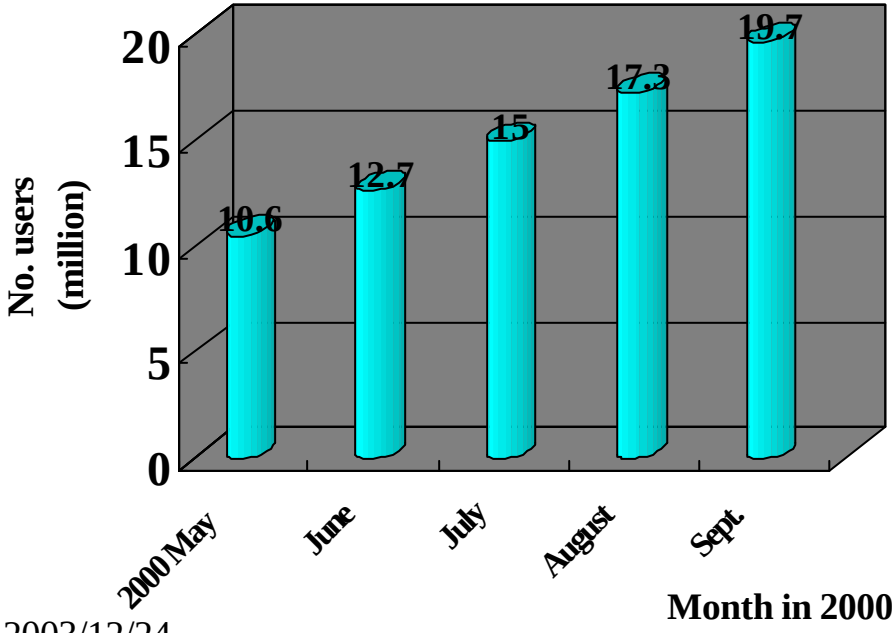


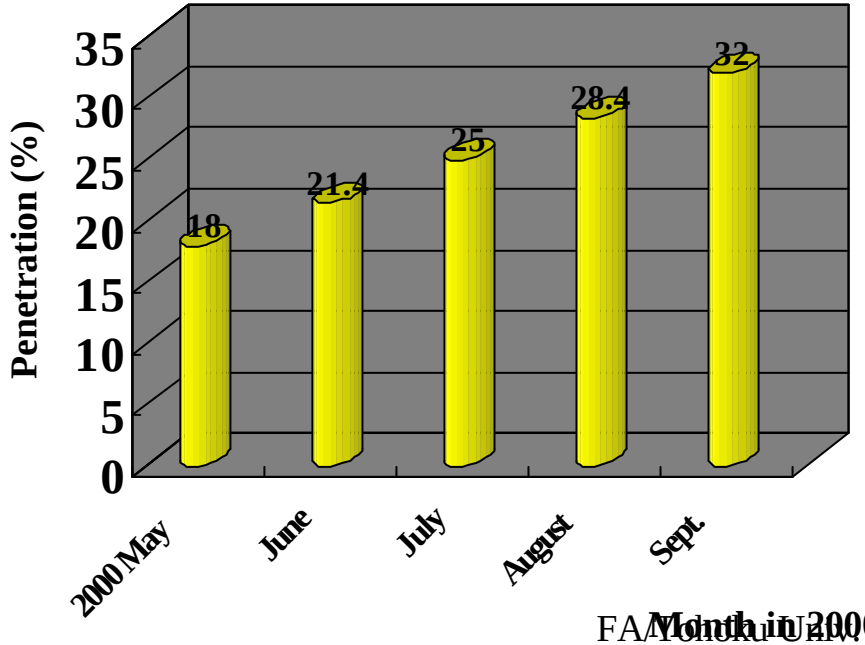
Mobile Internet Markets are Steadily Growing

- No. of mobile and PHS users
  - Total: 61.6M as of Sept. 2000
    - Mobile: 55.7M
    - PHS: 5.9M
- No. of users using Internet services
  - Total: 19.7M as of Sept. 2000
    - i-mode: 12.7M
    - Ezweb, J-sky: 7.0M
- Ratio of mobile Internet users: 32%

Data User Penetration

- User has started to use a mobile terminals as a data terminal as well as phone.
- Number of data users is increasing by more than 20 millions each month. Growth of data penetration is significant.





Can 2G Systems Cope With Increasing Demands of Mobile Multimedia Services?

- **Answer is a small YES. 2G systems optimized to realtime voice services have limited capabilities to provide richer multimedia services. Much faster data channels are necessary.**

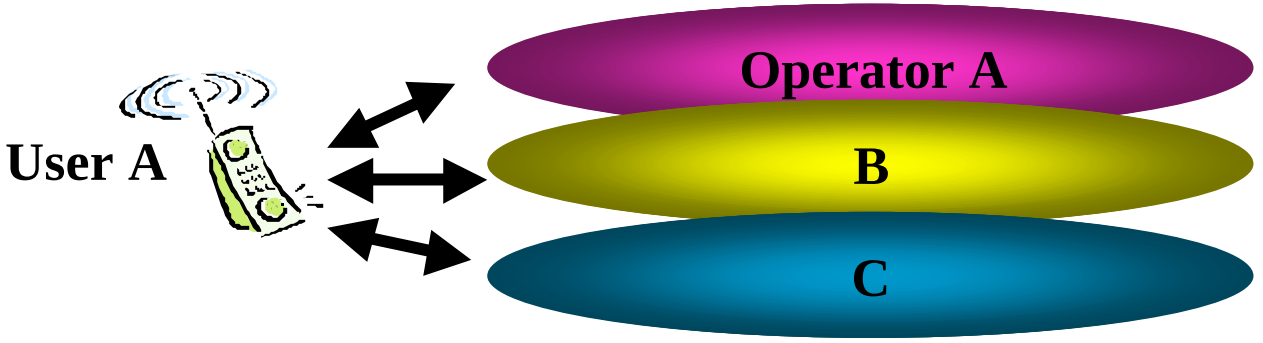
	PDC (1993.3)	GSM (1992)	TIA(USA) IS136	TIA(USA) IS95
Bandwidth (MHz)	800/1500	800/1900	800/1800/1900	
Wireless Access	TDMA	TDMA	TDMA	CDMA
Carrier Spacing (kHz)	25	200	30	1250
No. CH/Carrier	6	8	3	Max 64 (FL)
Speech Codecs (kbps)	5.6	22.8	13	8 (variable rate)

Evolution into Rich Multimedia Networks

- **Fixed**
  - **Metallic cables**
    ISDN: 64kbps
    ADSL modem: 10Mbps@3-4km from switching office
  - **Optical fiber cables: >100Mbps**
- **Mobile**
  - **3G systems (IMT2000)**
    < 2Mbps (starting from 2001)
  - **4G mobile systems**
    < 100Mbps (starting around 2010)

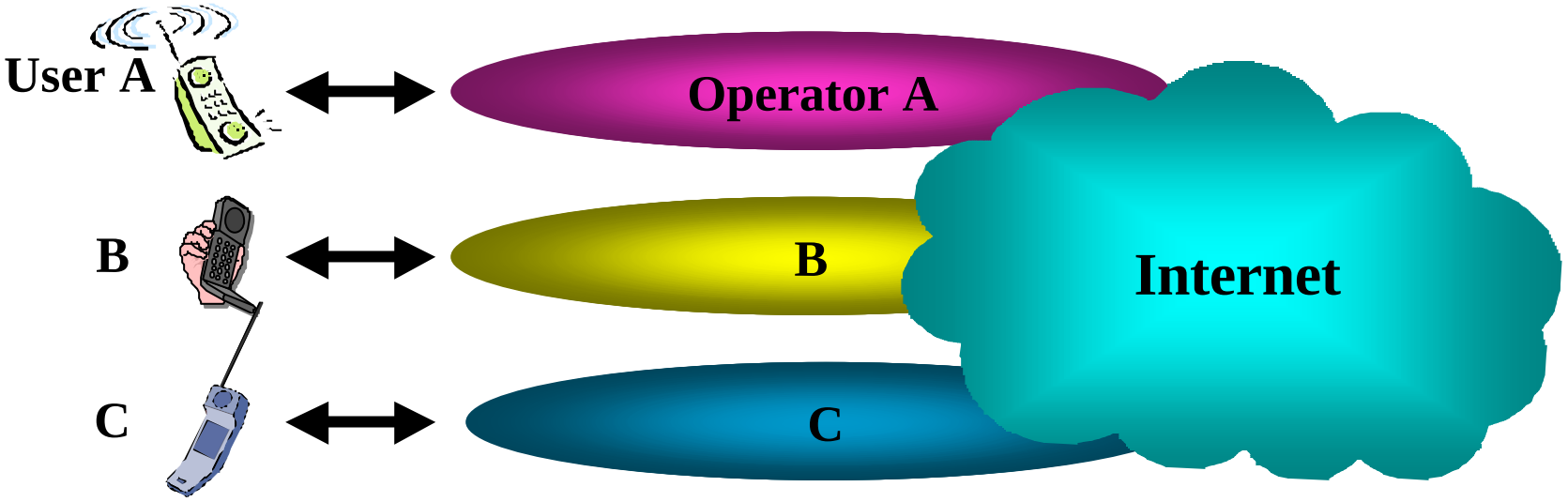
Terminal Future

- We are approaching an era of more than one wireless terminals per person.
- Why not one global phone? One can subscribe multiple operators' own services. How to make this possible?
  - A single air-interface technology
  - Software radio technology



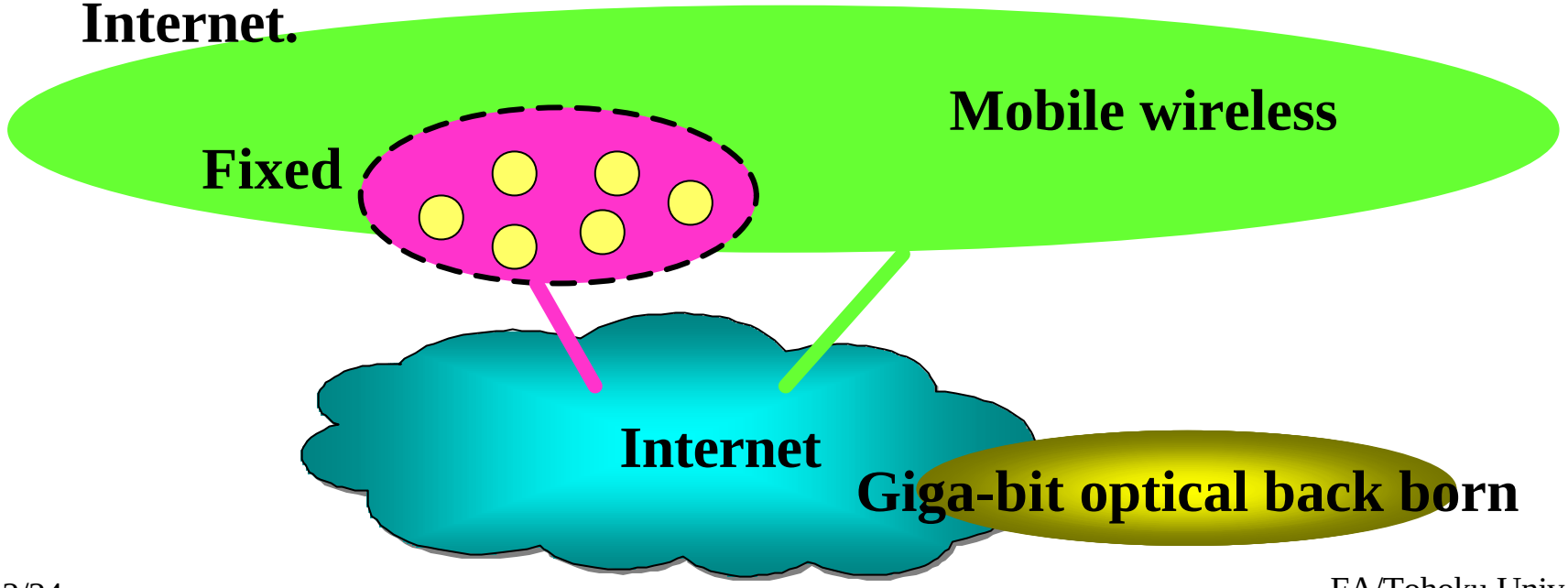
Terminal Future

- Or one phone dedicated to a single operator that provides full connection to Internet. Of course, each operator can charge different air-charge and also provide different type of additional services from others.



New Role of Fixed Networks

- **Mobile networks will take place of CONVENTIONAL fixed networks role, probably soon, with emphasis on Internet services.**
- **Fixed networks will evolve into Mega-bit multimedia information networks of INFO KIOSK connected to Internet.**



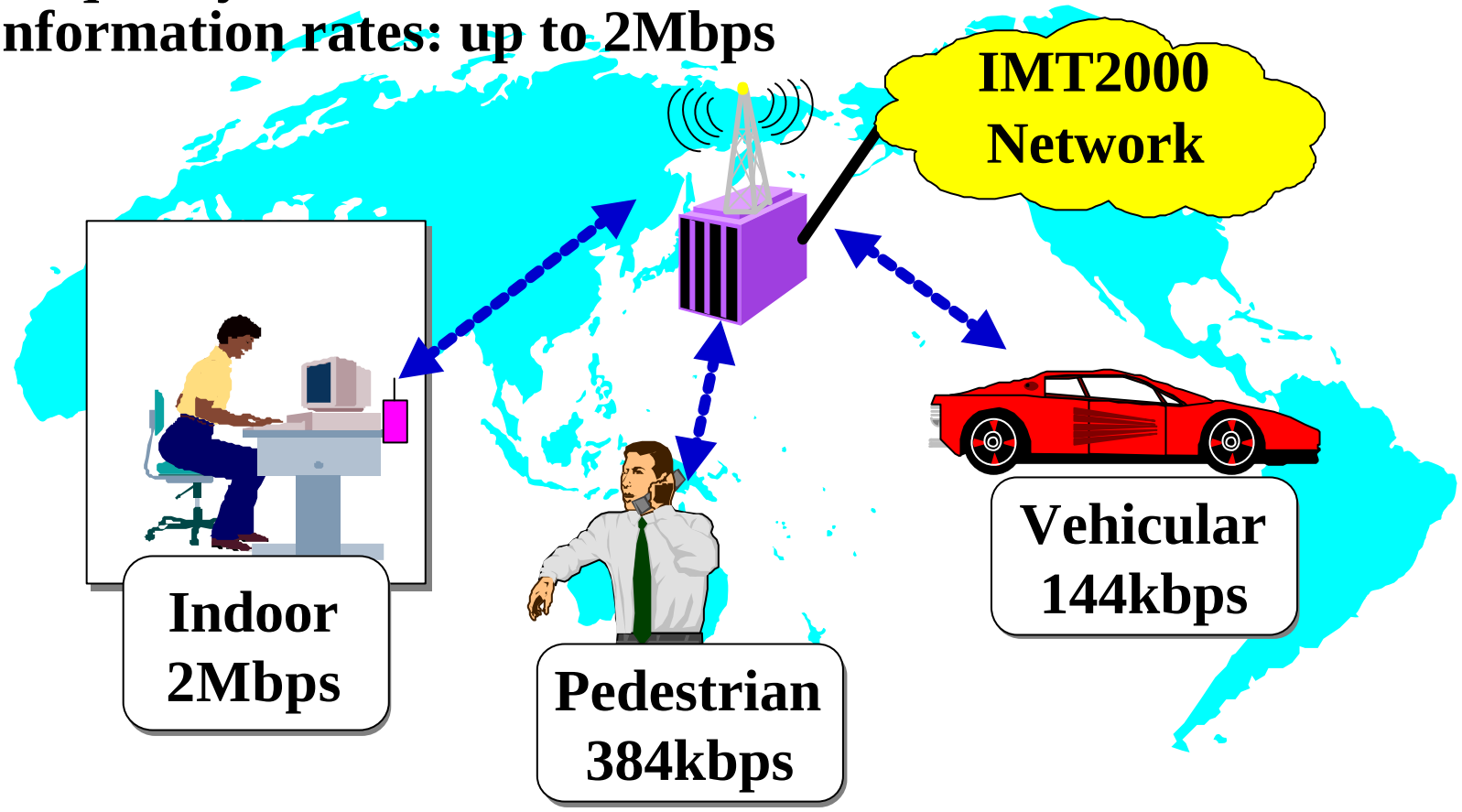
Evolution into 3G Systems (IMT2000)

What Is 3G?

- Why necessary?
  - Explosive expansion of markets
  - Mobile multimedia communications
  - Global standard
    - ✍Big business chances
    - ✍Lower cost due to mass markets
- Which services?
  - Unknown, but services indicated by the success of “i-mode”
  - Point-to-point, point-to-multi points, broadcasting services

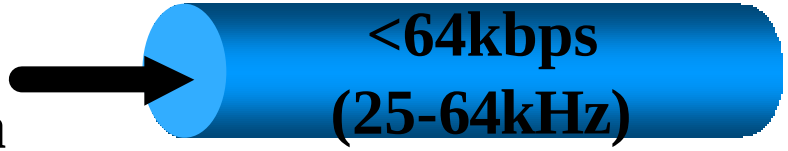
IMT2000 Capability

- Planned to deploy in May 2001
- Frequency band:2GHz band
- Information rates: up to 2Mbps

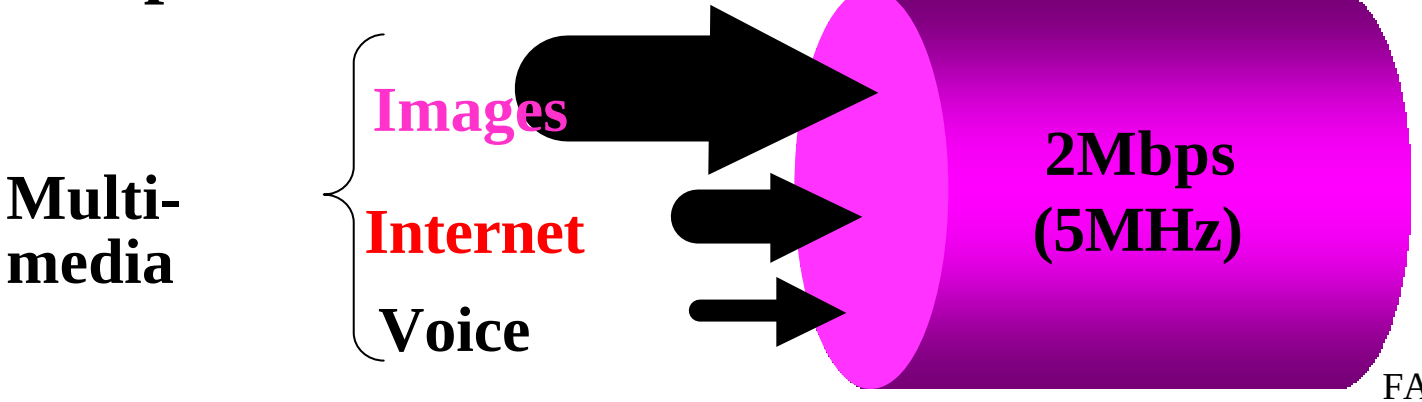


Differences Between 2G and 3G Systems

- Flexible offer of mobile multimedia services
  - Voice/fax/data
  - Wideband data services (high speed Internet/high quality images)
- 2G provides slow bit pipes

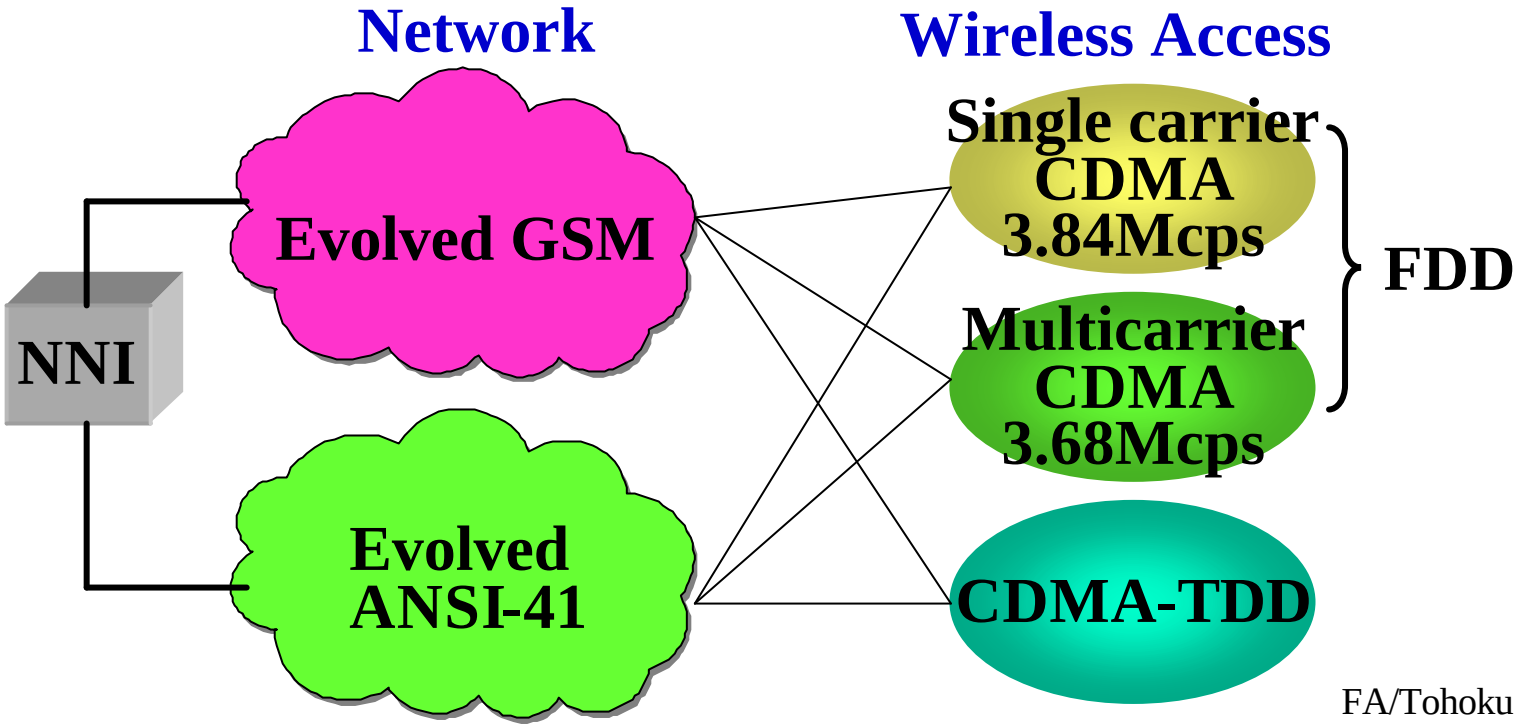


- 3G provides much faster bit pipes



Direct Spreading CDMA (DS-CDMA) Becomes Main Stream

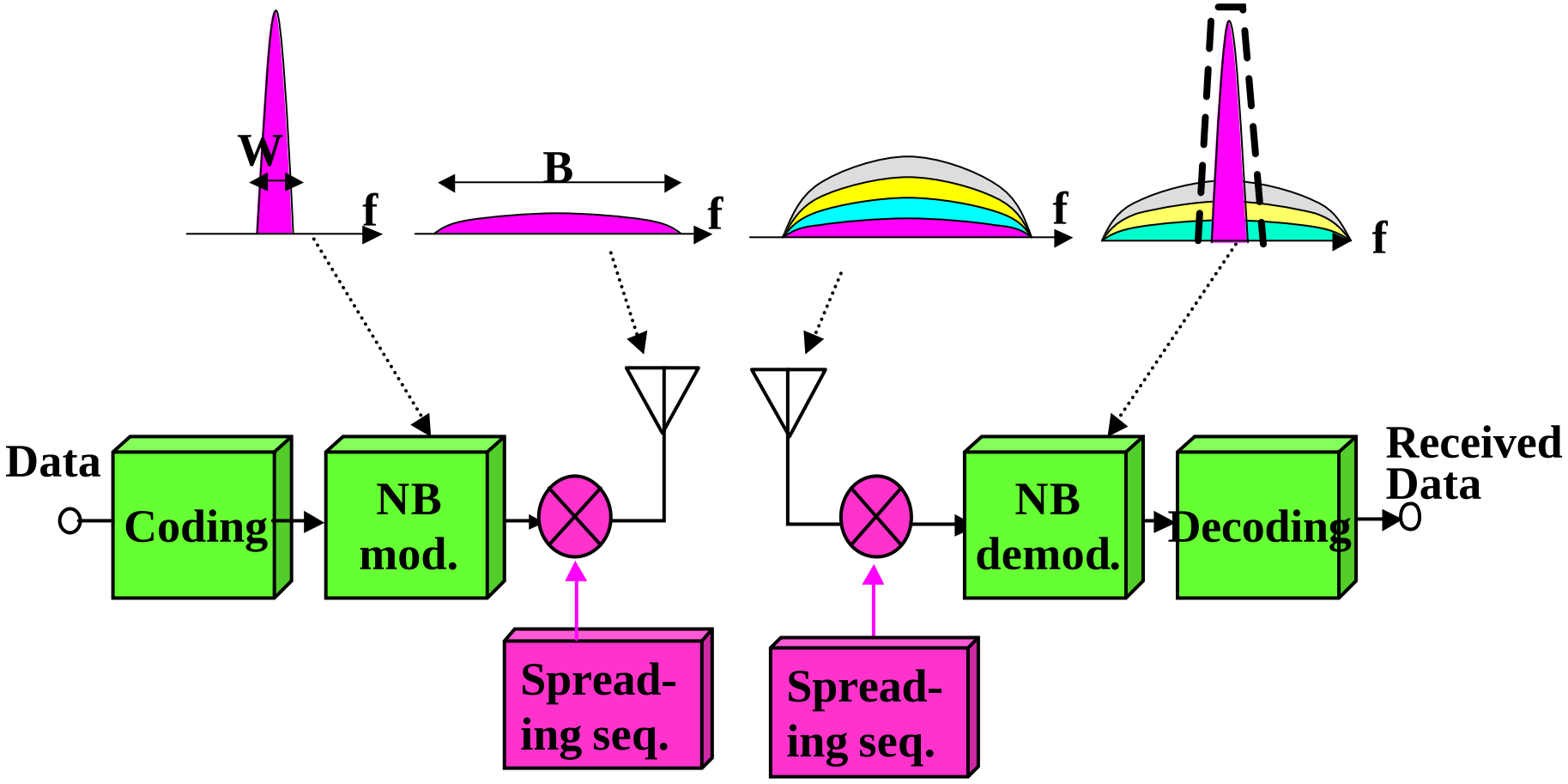
- Single carrier CDMA (W-CDMA), successor to PDC and GSM, will dominate markets in Asia and Europe.
- Successor to cdmaOne is multicarrier CDMA (cdma2000).



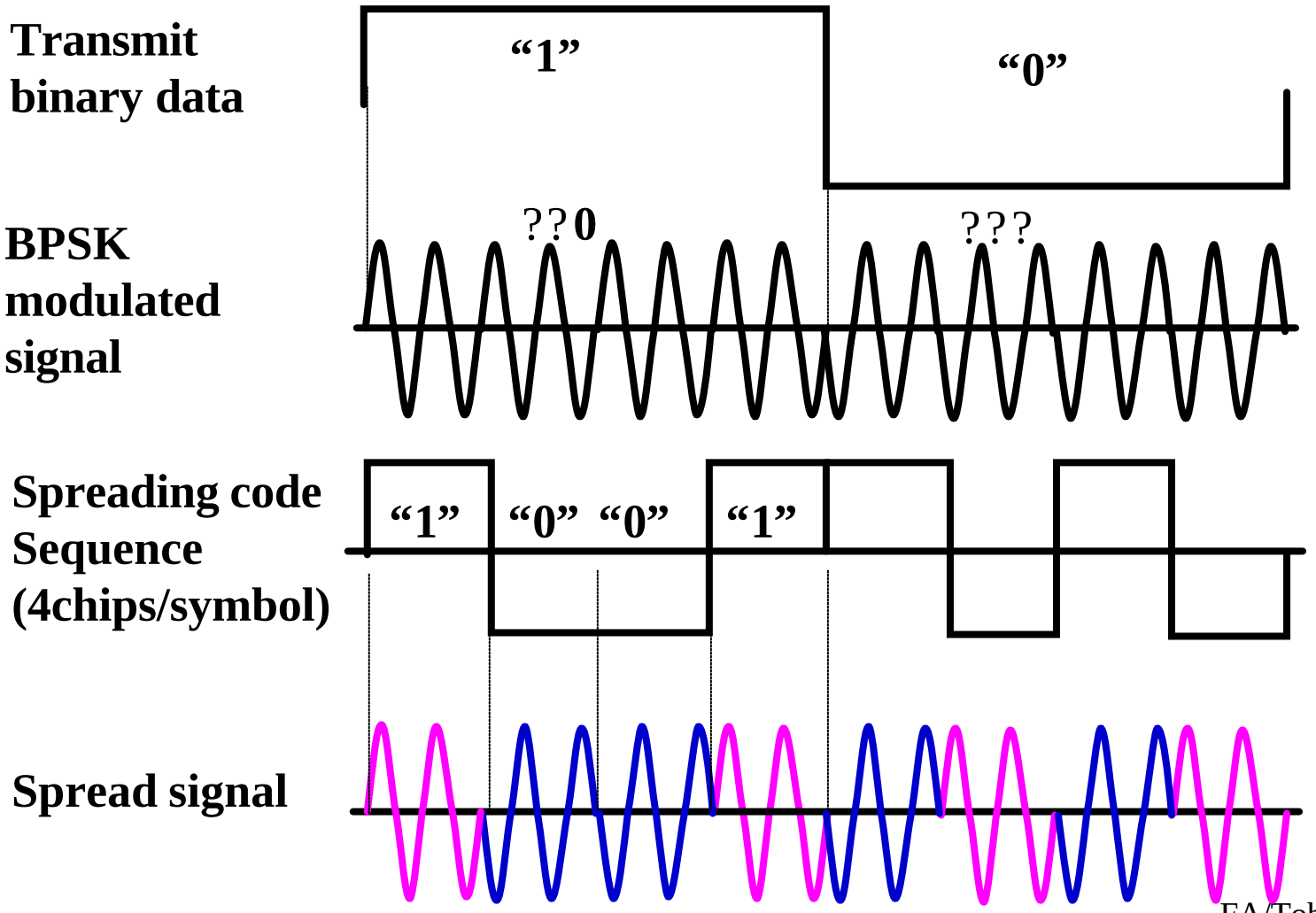
Coffee Break

DS-CDMA

DS-CDMA Wireless Access

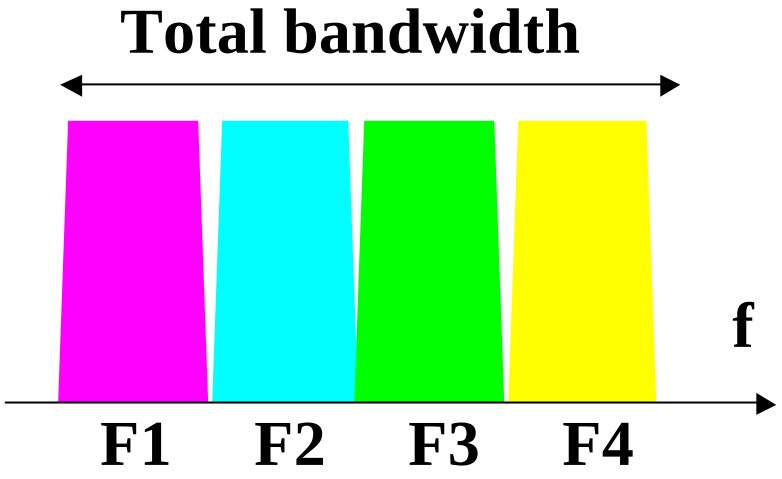


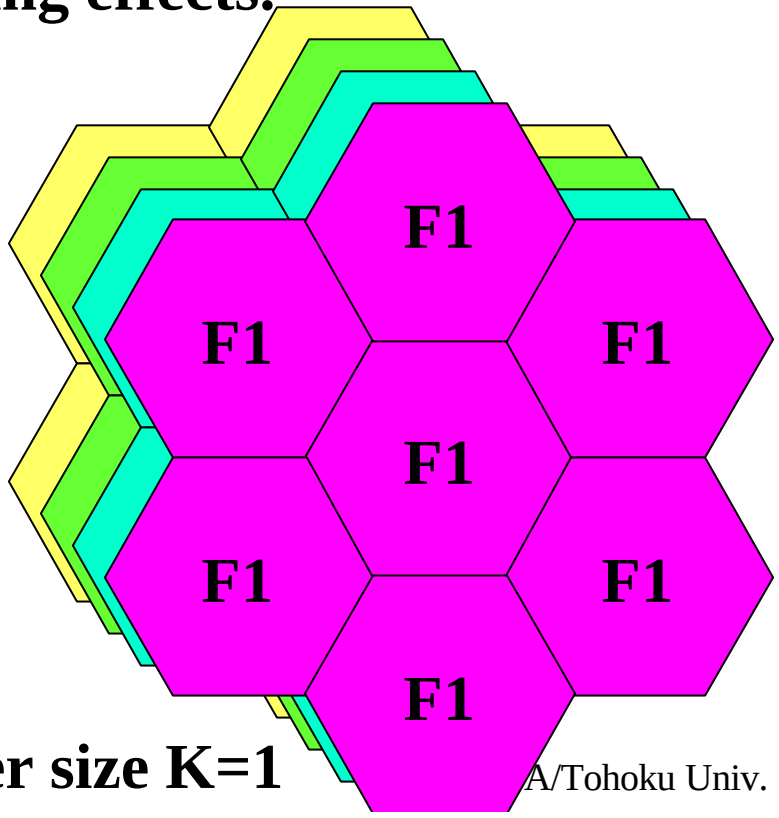
Spreading Process



Celluar CDMA

- **Single frequency reuse to improve spectrum efficiency. TDMA should use 3 different carriers at least to cover a service area.**
- **Soft handoff to reduce shadowing effects.**





Cluster size K=1

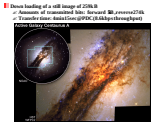
Enhancing W-CDMA

- Large Interference produced by mobile multimedia users
  - High speed users produce large interference to low rate users (voice users)
  - Increases in multimedia users decreases no. of users
- Promising techniques
  - Interference cancellation

    Reproducing the interferences to subtract from the received signal
  - Adaptive antenna array
    - Equivalent adaptive cell sectorization
    - Beam nulls to reduce the interference from high rate users

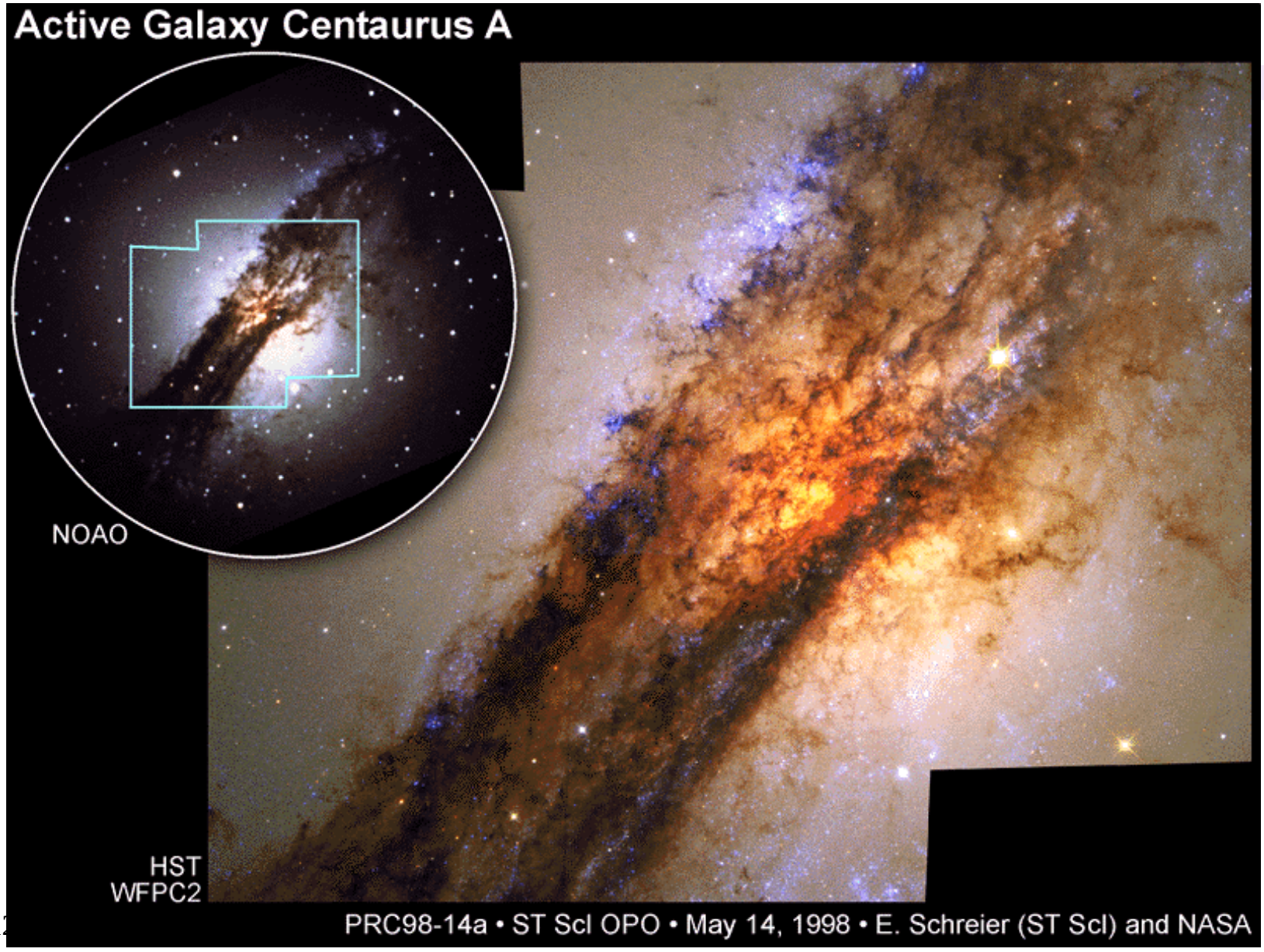
Ultra-high Speed Wireless Links Will Be Required

- **Ever increasing information volume**
  Down loading of high quality still images, moving images will be common
- **Tremendous long transfer time over the air**
  - **A 275MB still image needs 4min@9.6kbps and 3.24 seconds@1Mbps to download.**
  - **Users are not patient to wait?**



- **Widening asymmetric traffic between forward and reverse links (RL rates<<FL rates)**
  - **More than several tens higher rates will be required for forward links for downloading images from a Web site.**
  - **Maybe uploading can be allowed to take a longer time.**

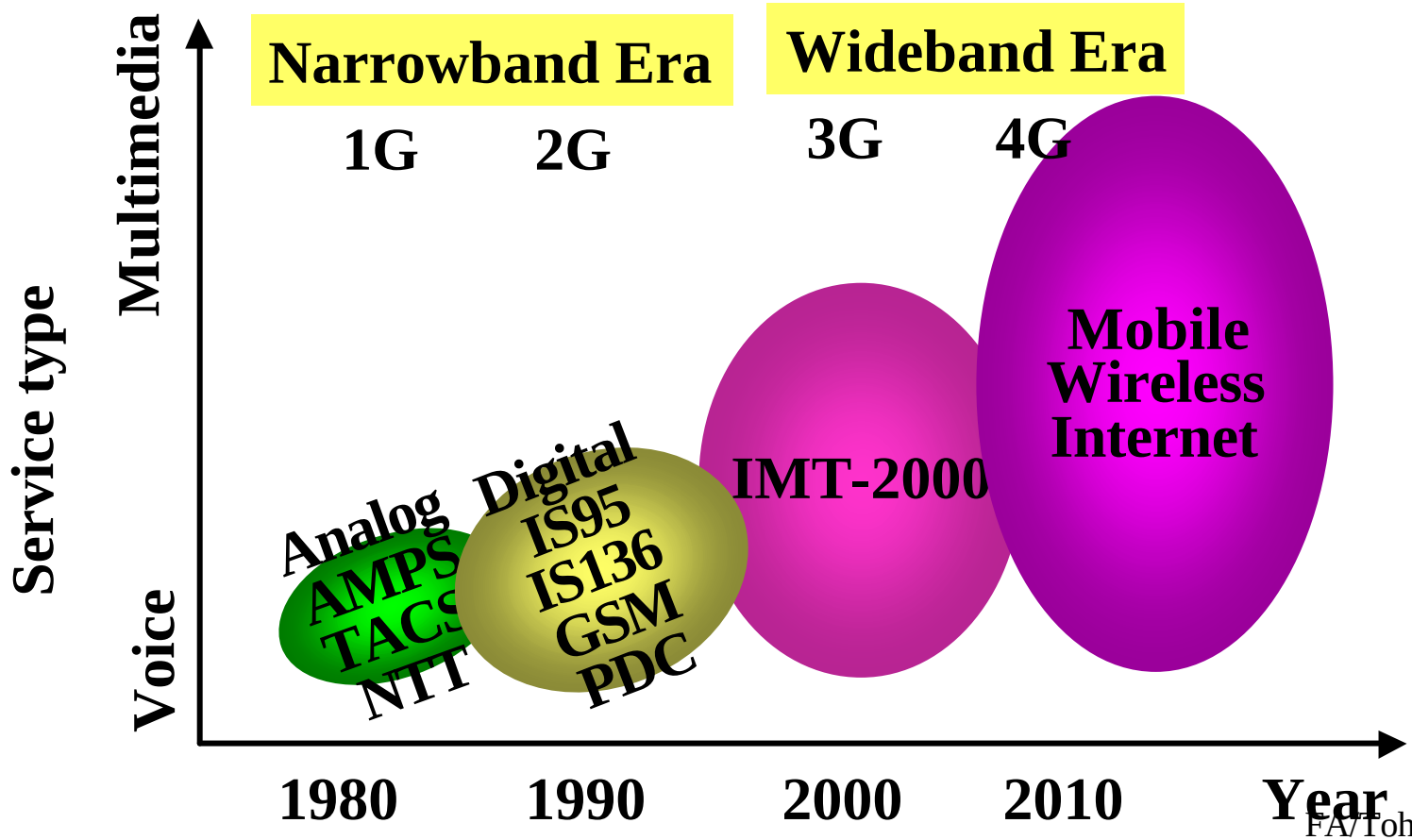
- **Down loading of a still image of 259kB**
  - ✍ **Amounts of transmitted bits: forward 5kB, reverse 274k**
  - ✍ **Transfer time: 4min15sec@PDC(8.6kbps effective throughput)**



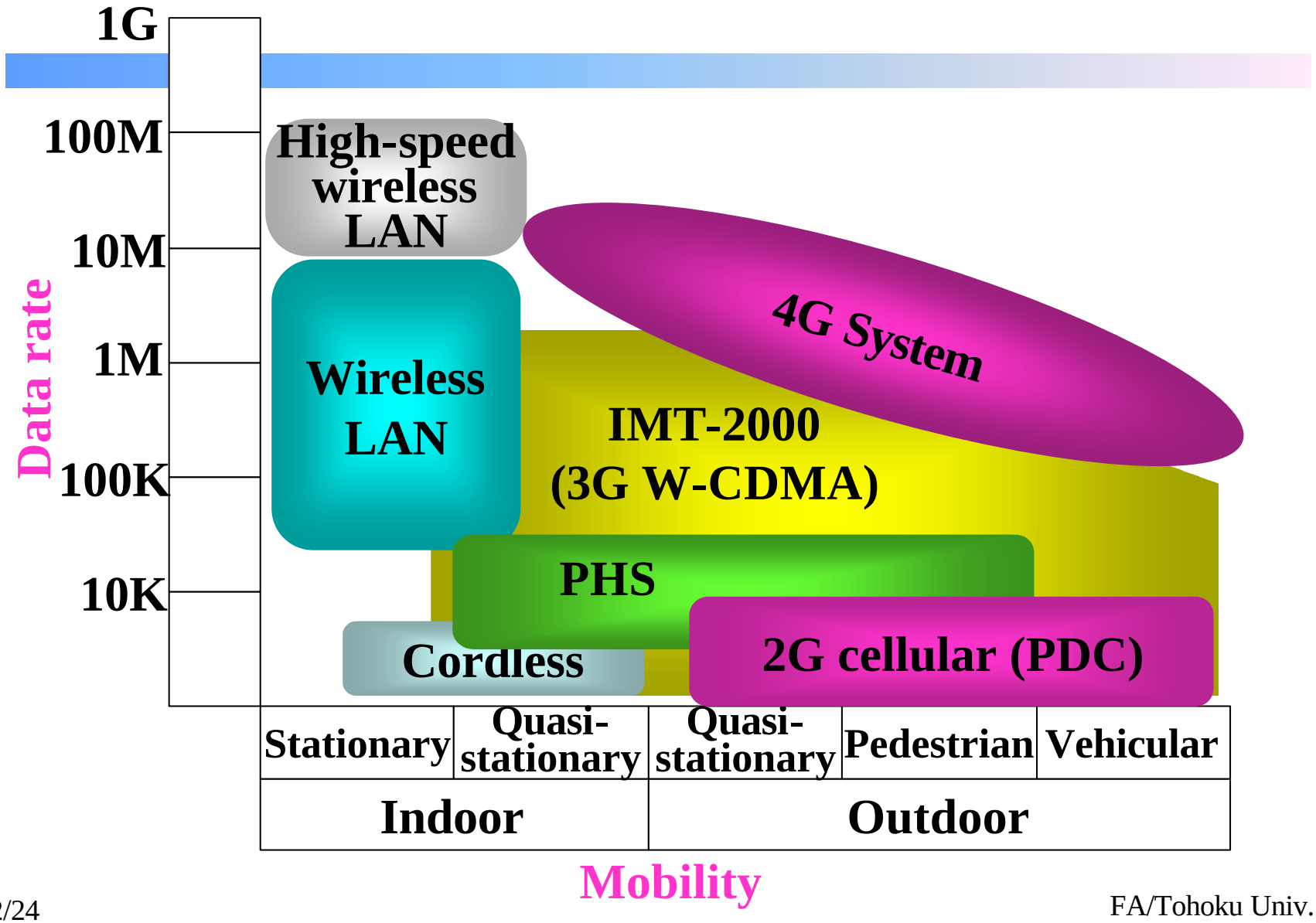
Post 3G Era
-4G Mobile System -

Evolution into 4G

- Every 10 years, a new system appeared according to evolution of our society

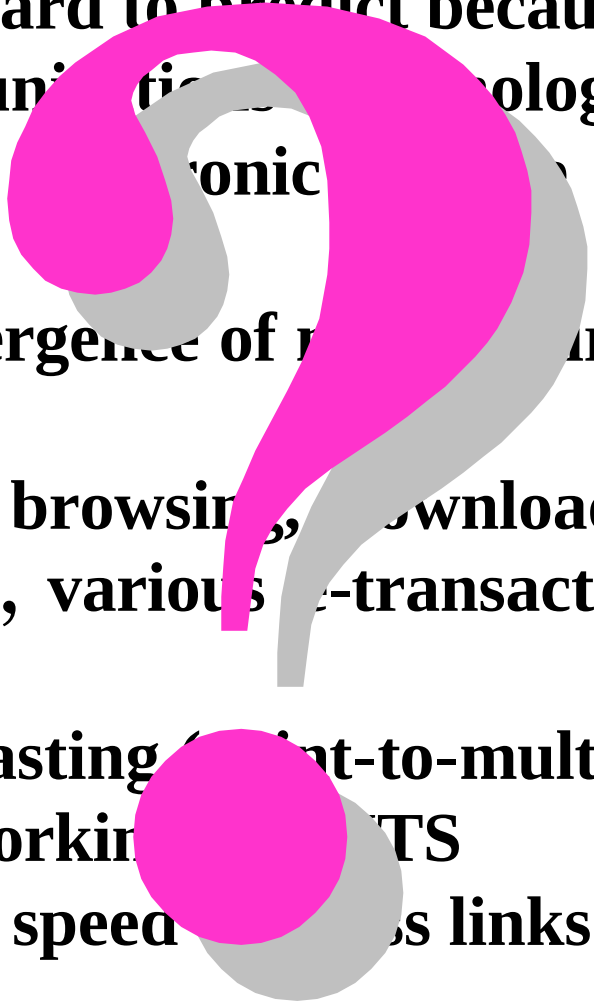


Target Area of 4G Systems



4G Services

- It is very hard to predict because of fast advancement of communications technologies and dynamically expanding electronic business environments due to Internet.
- Real convergence of mobile wireless and Internet will happen
  - WWW browsing, downloading, e-mailing, Voice over IP, various e-transactions, Location related services
  - Broadcasting (point-to-multipoints) services
  - Inter-working with WLAN
- Ultra-high speed wireless links are required



Evolution from 3G to 4G

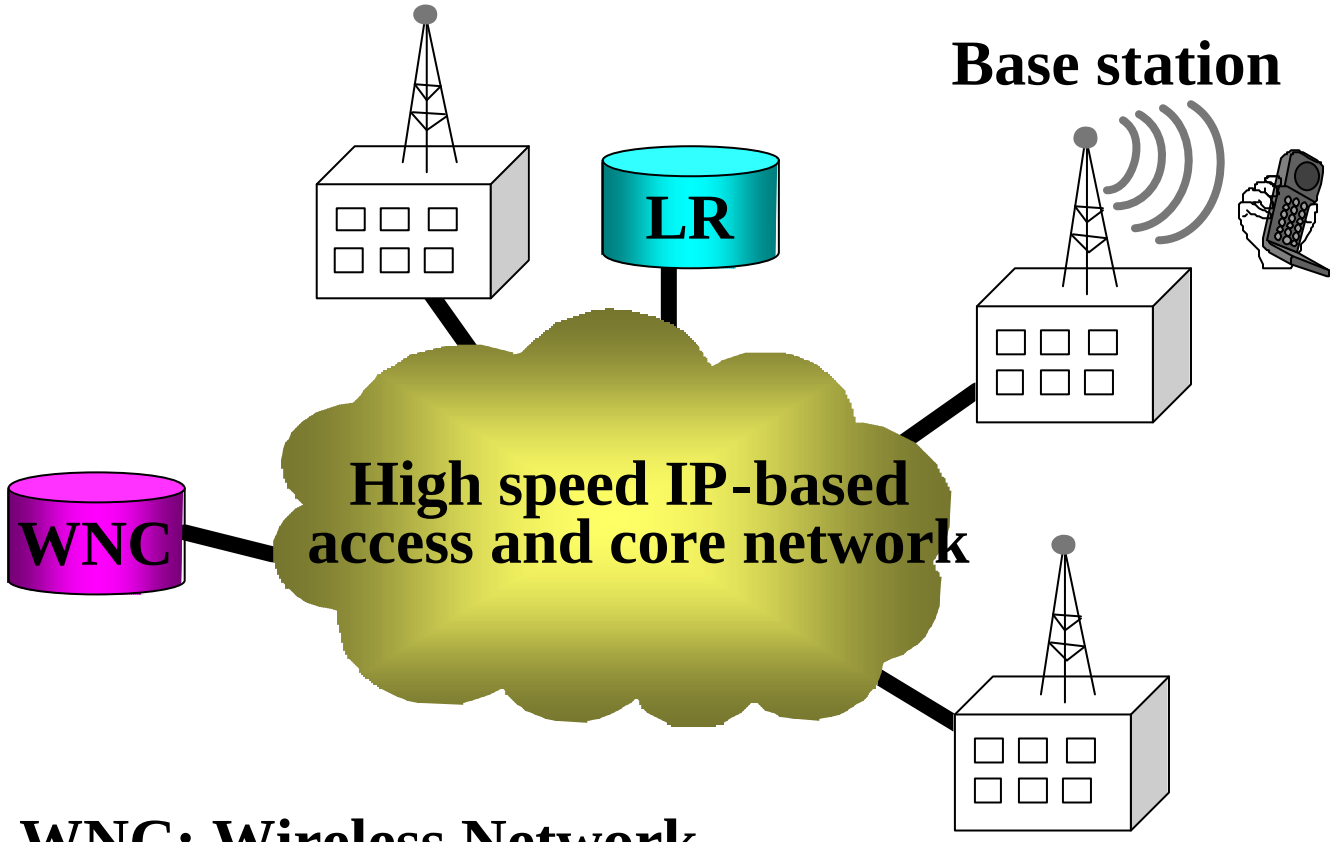
- **Core-network will be fully IP-based to provide rich Internet services to mobile users.**
- **However, this may happen in 3G systems.**

	1G	2G	3G	4G
Wireless Access	**Analog**	**Digital**	**Digital**	**Digital**
	FDMA	**TDMA •DS-CDMA**	**DS-CDMA**	**Mega-bit wireless (OFDMA?)**
Major Services	**Voice**	**Voice**	**Voice**	**Voice over IP**
		Internet (text only)	**Internet (text, images)**	**Rich Internet?**
Core-network	**Circuit-switched**	**Circuit-and packet switched**	**Circuit-and packet - switched**	**IP-based (IP over ATM?)**

Technical Issues of 4G Systems

- Optimized to high speed IP packet transfer
  - Pedestrian: 100Mbps
  - Vehicular: 10-20Mbps
- Flexible multiplexing of wide ranges of information rates
  - Packet-based link design
  - Mixture of random and reservation random asccess
  - Flexible assignment of wireless bandwidths between forward and reverse links
- Quality (delay, transmission rate)
  - Environment adaptive best effort type transmission with guaranteed minimum rate
- Wireless security

IP-based 4G System

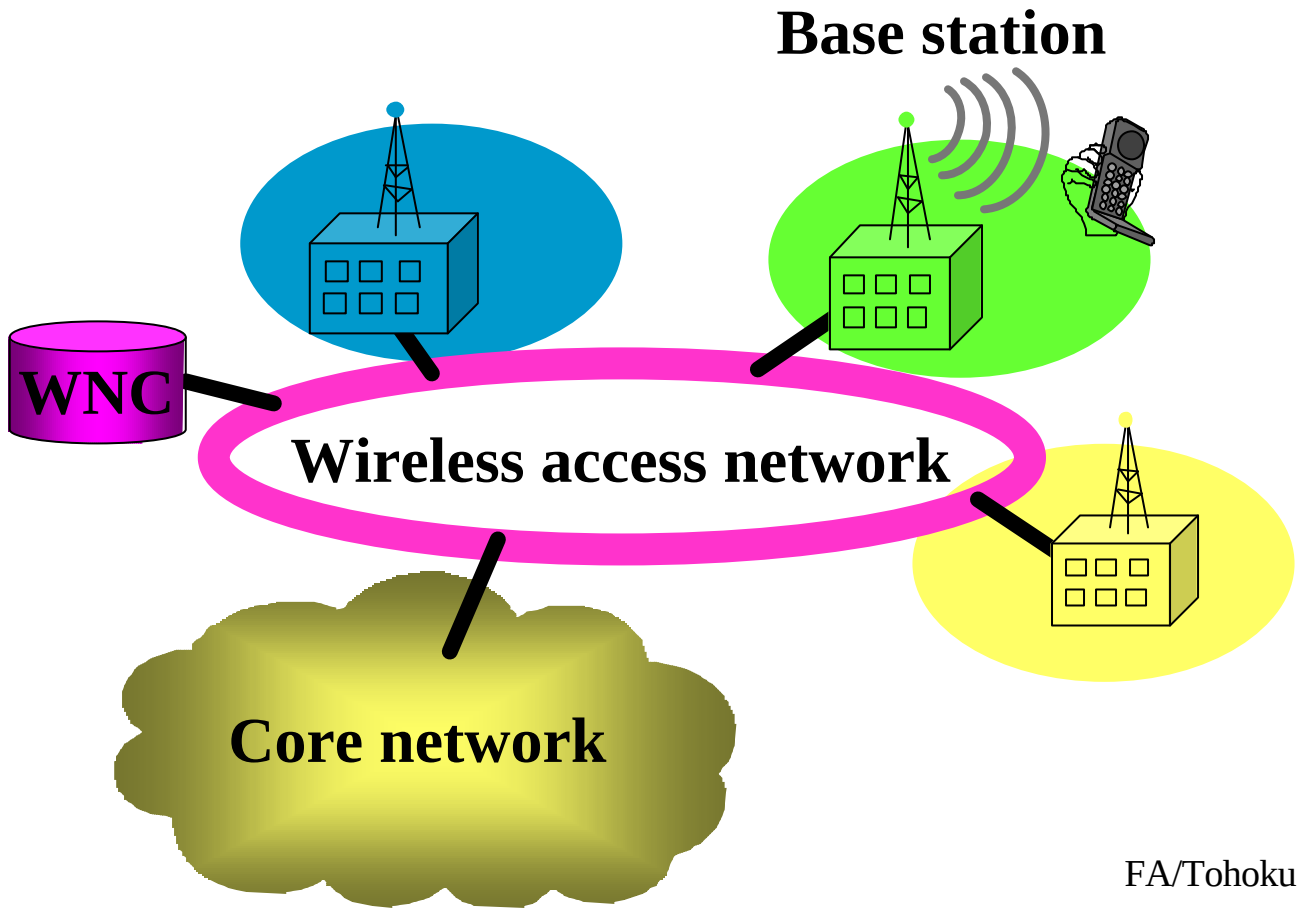


WNC: Wireless Network Controller

LR: Location Register

Wireless Access Network

- **Wireless access networks will be built on similar architecture to wireless LAN.**



4G Mobile Wireless Technology

Mega-bit Mobile Wireless

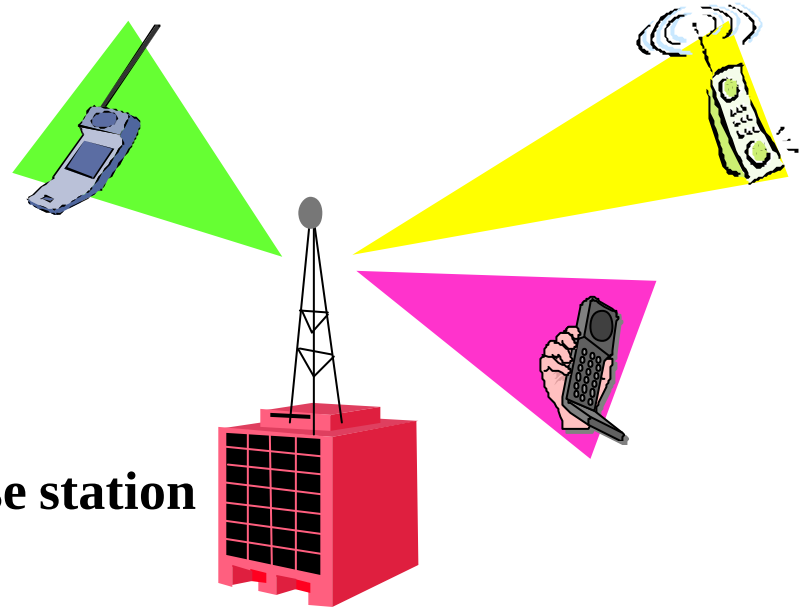
- Wireless access
  - Data rate
    - Pedestrian: 100Mbps
    - Vehicular: 10-20Mbps
  - Asymmetric FL and RL
    - FL (B-M):100Mbps
    - RL (M-B):Probably <100Mbps
  - Random access optimized to IP packet transfer
- Wireless network
  - Nano-cell (10-30m radius) structure to cope with increasing path loss
  - Fast handoff procedure for packet

Wireless Channel Limitations -1

- **Power limitation due to [$f^{2.6}$ x transmission rate] law**
  - **Peak transmission power for 100Mbps at 5GHz is about 135,000 times that of 8kbps at 2GHz , e.g., 1W→135kW. This cannot be allowed.**
  - **Cell should be reduced by about 29 times (nano-cell, e.g., 1,000m→34m cell).**
  - **Dynamic and fast variations in path loss. Statistic-based cellular concept cannot be applied. Will the cellular concept disappear?**
- **New wireless network design and wireless technology that allows significant reduction in mobile transmit powers.**
  - **Distributed *nano-cell* receive station network**

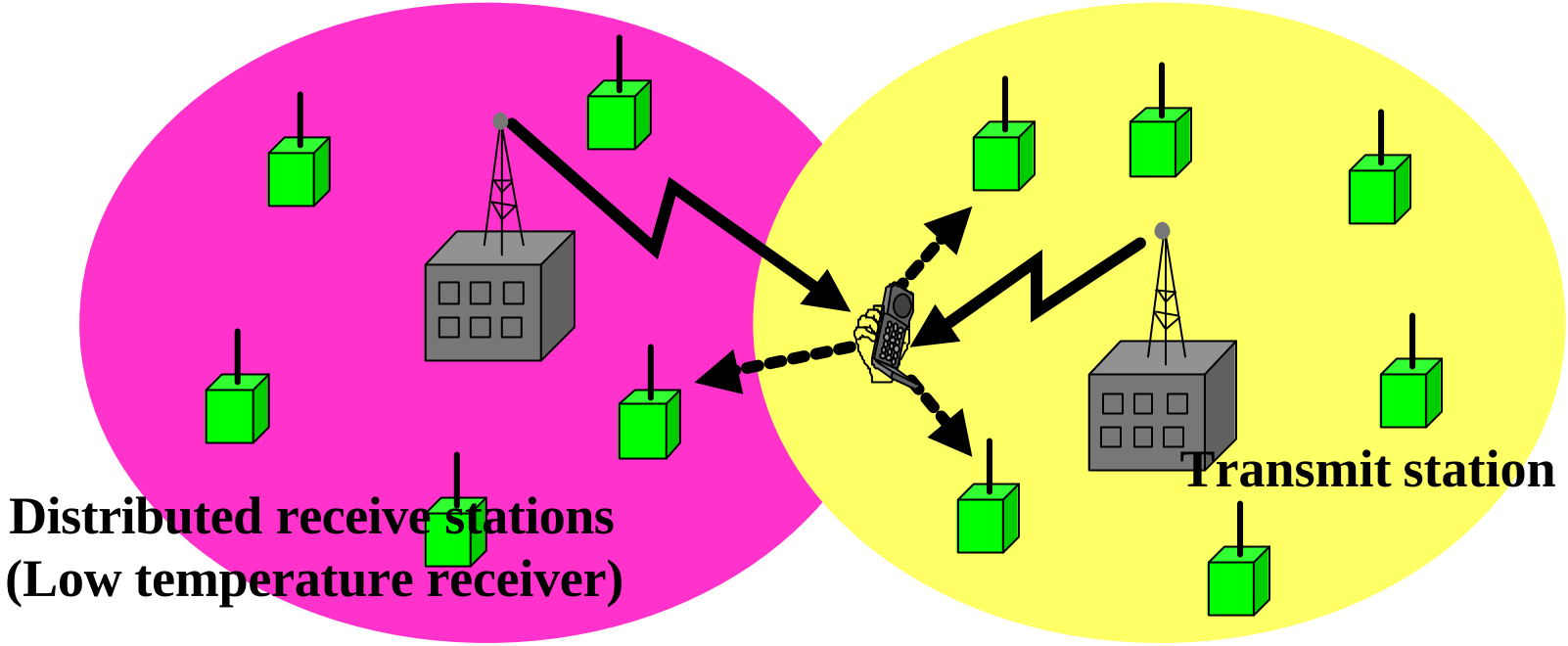
Limitation of Antenna Array with Narrwobeam

- **Narrow beam is directed toward desired user to achieve:**
  - **Reduction of interference from/to other users**
  - **Increased antenna gain in inverse proportion to antenna beam width**
- **However, additional gain may be 10-20dB and is not sufficient.**



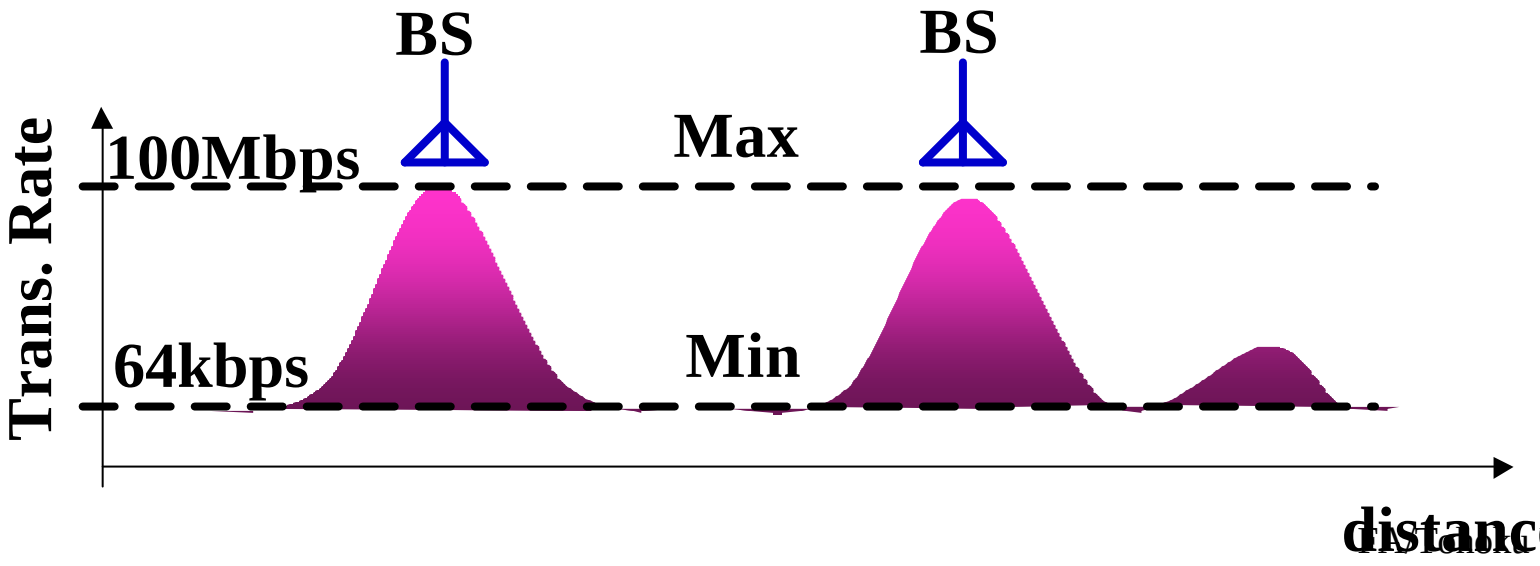
Introduction of Distributed Nano-cell Receive Station Network

- Fundamental change in wireless network architecture
- Separation of transmit and receive functions
- Flexible deletion and addition of receive stations



Introduction of Environment-Adaptive Transmission

- **Best effort type adaptive transmission. Always maximum achievable transmission rate depending on surrounding environment.**
- **Faster transmission rates if closer to base stations or better propagation conditions.**
- **Guaranteed minimum rate of e.g. 64kbps.**



Mega Wireless Stand

- At a place where Mega Wireless Stand is available, data transfer can be done almost instantly at a speed of 100Mbps.
- At other places, data transfer can be performed at a maximum achievable data rate, i.e., best effort type adaptive transmission.

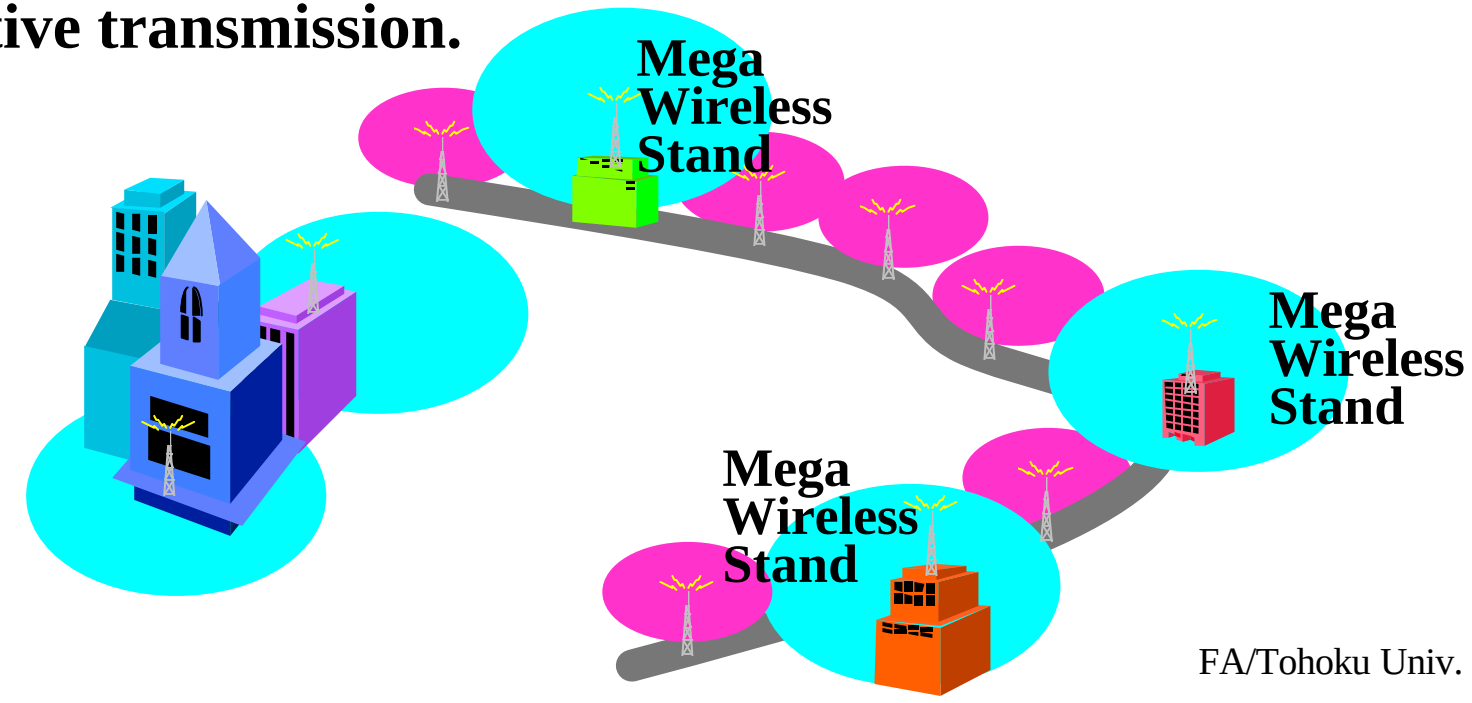
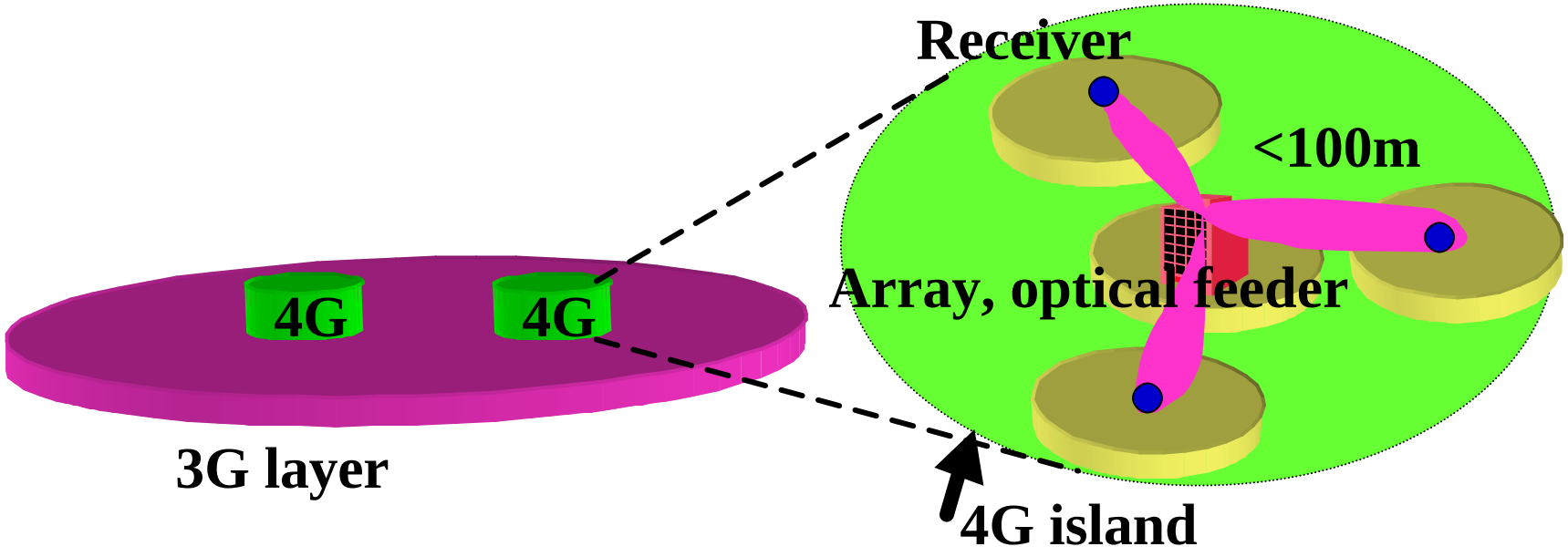


Image of 4G Cell Structure

- Only hot spot areas can be covered. Continuous services are available by overlay to 3G layer.
- Inside 4G island, array or optical feeder links connect many distributed receive stations.



Hand-off Issue

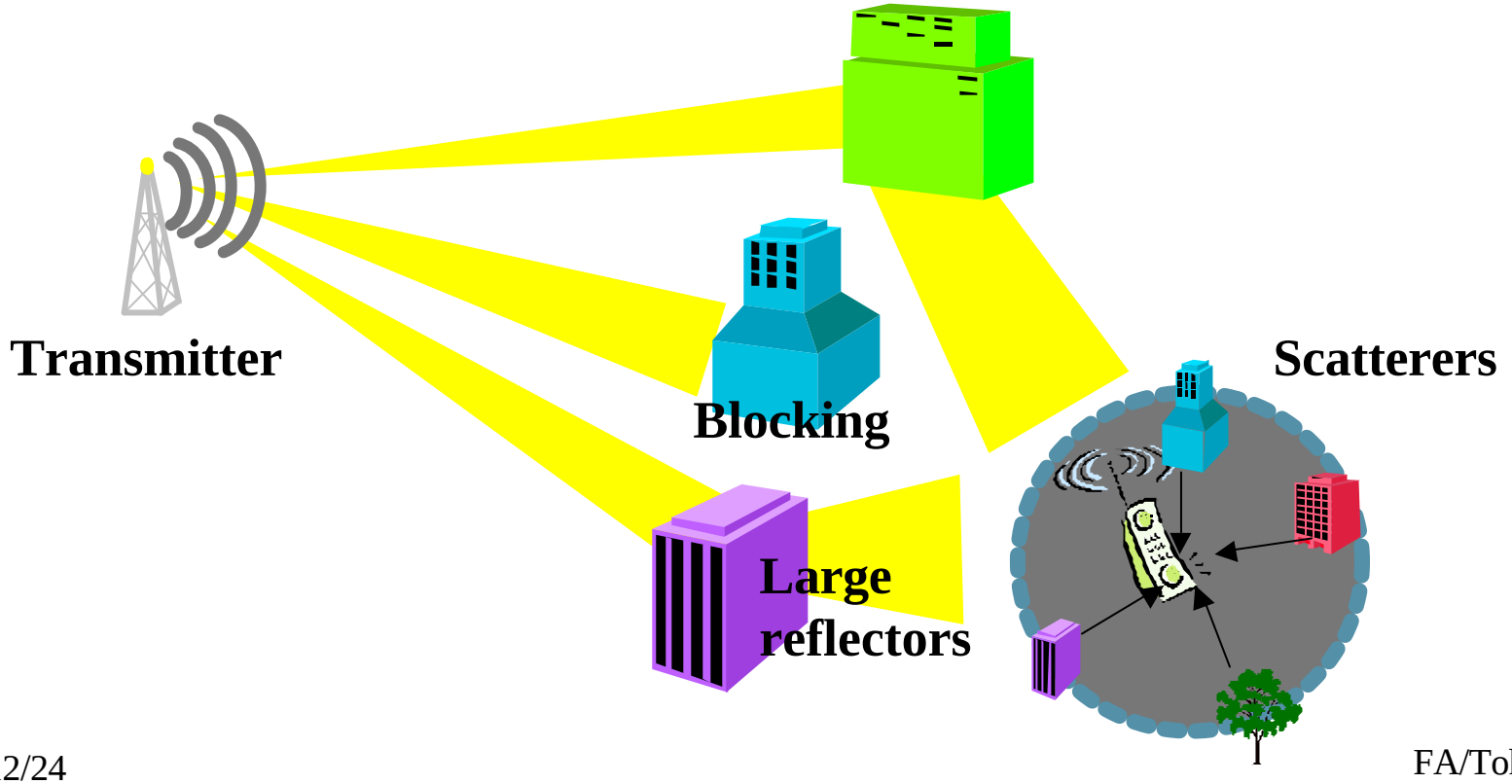
- **Packet hard handoff since transmission time is very short.**
- **A packet from mobile terminal is received multiple receive stations to be combined or selected at a central station.**
- **The same packet is transmitted from multiple transmission stations in a predetermined order.**

Wireless Channel Limitations-2

- High speed wireless communications over a bandwidth wider than 100MHz
- Severe frequency selective fading channel
  - Fine propagation structure can be seen. Propagation parameters changes dynamically and rapidly.
- More than one wireless techniques must be combined
  - Bandwidth efficient modulation
  - Powerful channel coding
  - Adaptive antenna array
- Interesting question. Whether to spread or not to spread?

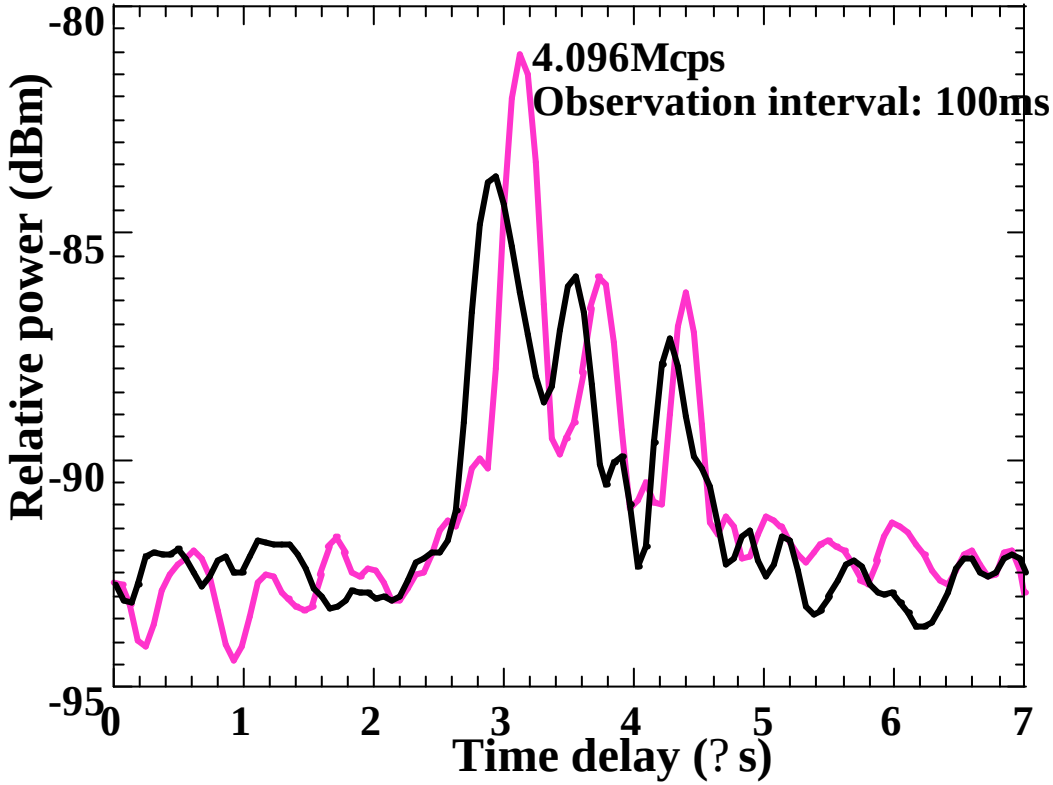
Multipath Propagation Channel

- **Transmit signal is reflected and diffracted by nearby buildings and trees. Interference among reflected and diffracted waves creates fading channel.**



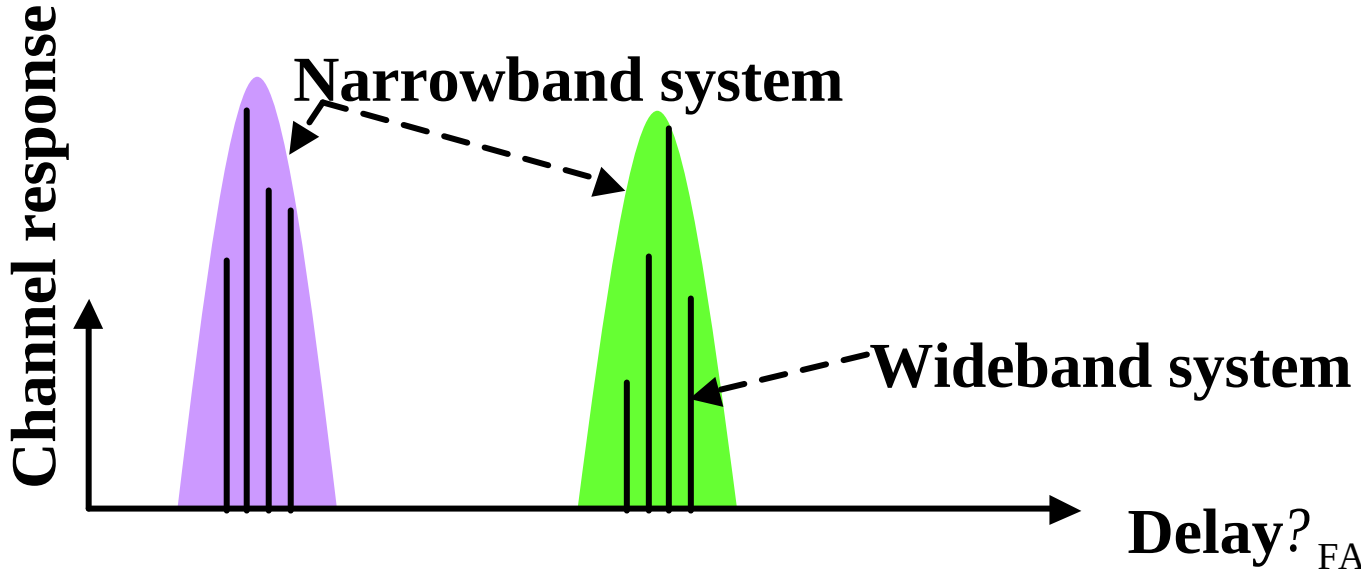
Measured Channel Response

- Multiple copies of the same transmit signal are received due to reflection of e.g. buildings.
- DS receiver resolves these copies and coherently combines to improve transmission performance.



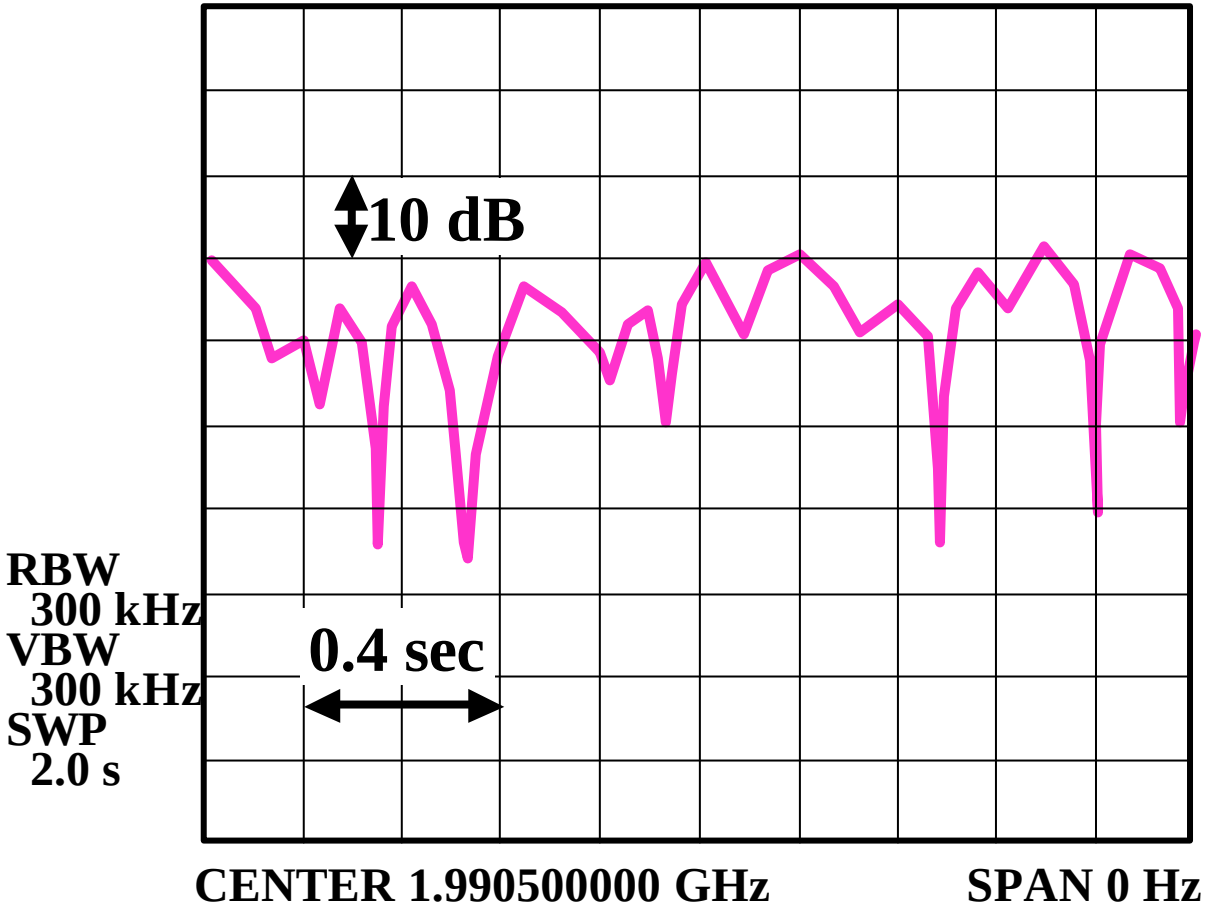
Problems of Spread Spectrum Communication (DS-CDMA)

- Lack of enough bandwidth for spreading
- Limitation on time domain processing (Rake)
  - Too many multipaths
  - Rake with finite number of fingers
    - Power loss
    - Degraded channel estimation



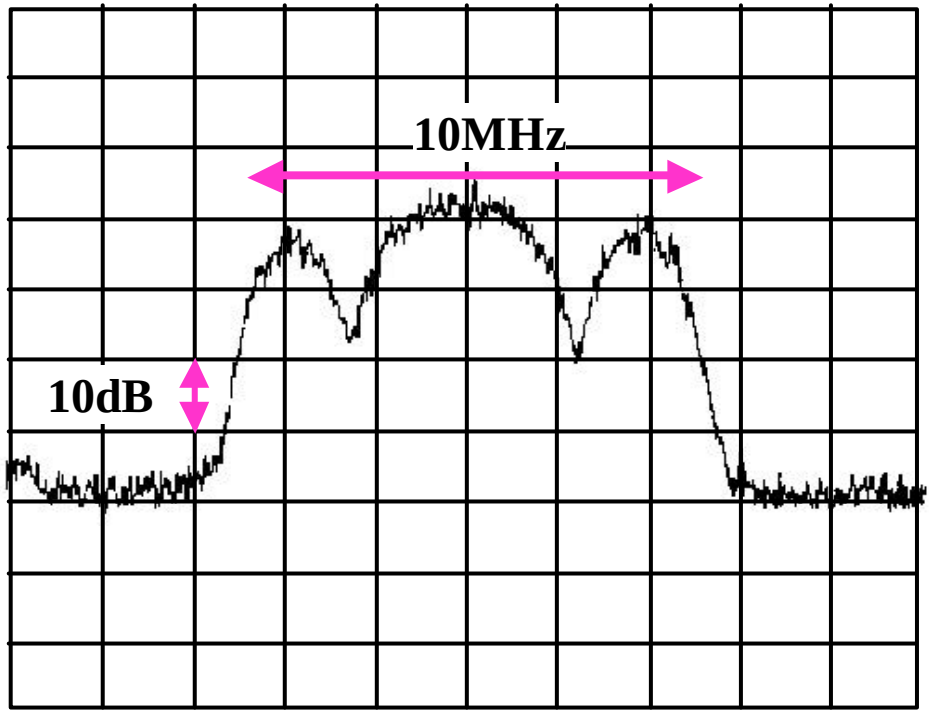
Time variations in Received Signal Power

Rayleigh fading (f_D=4Hz)



Measured Distortion of Signal Spectrum

- **When multiple paths with different time delays exist, the received signal spectrum is distorted.**

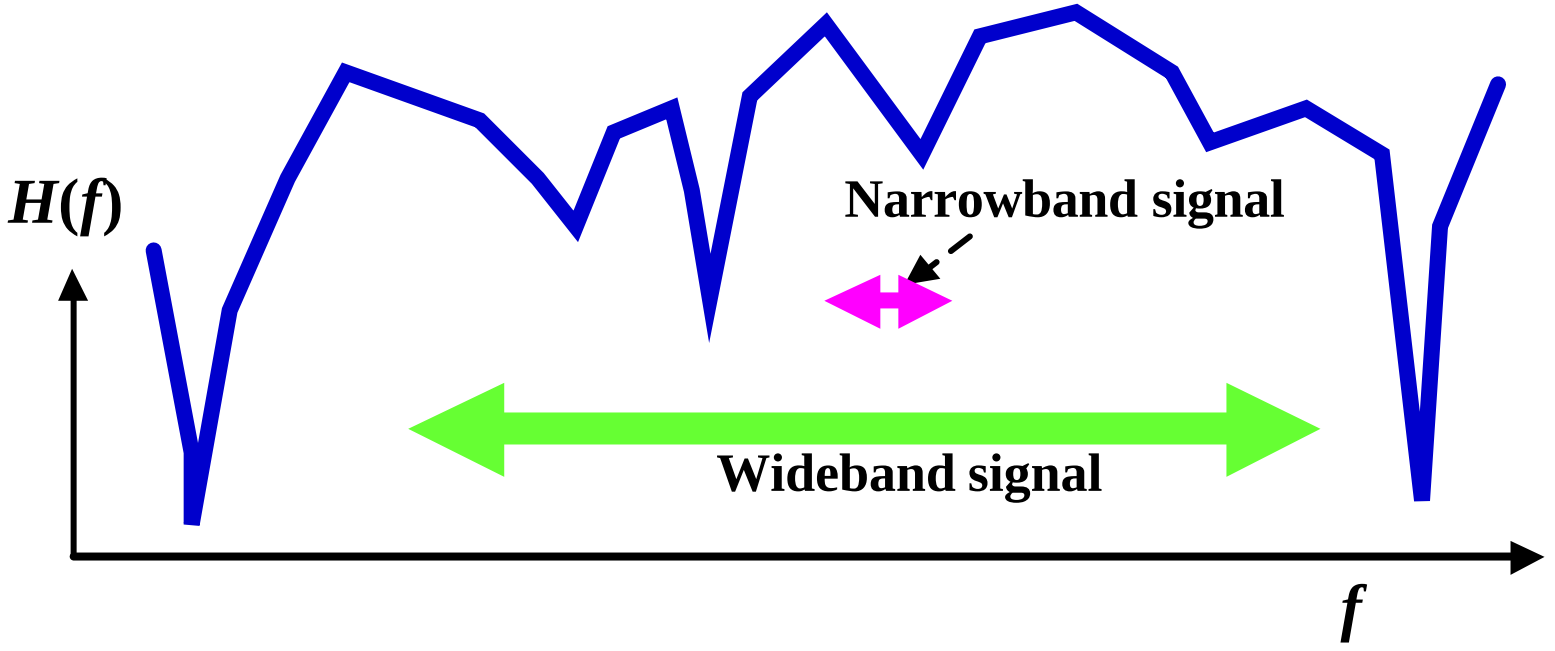


10MHz bandwidth
2-path channel
(0.2? s time delay)

SPAN
20.00 MHz
RBW
300 kHz
VBW
300 kHz
SWP
2.0 ms

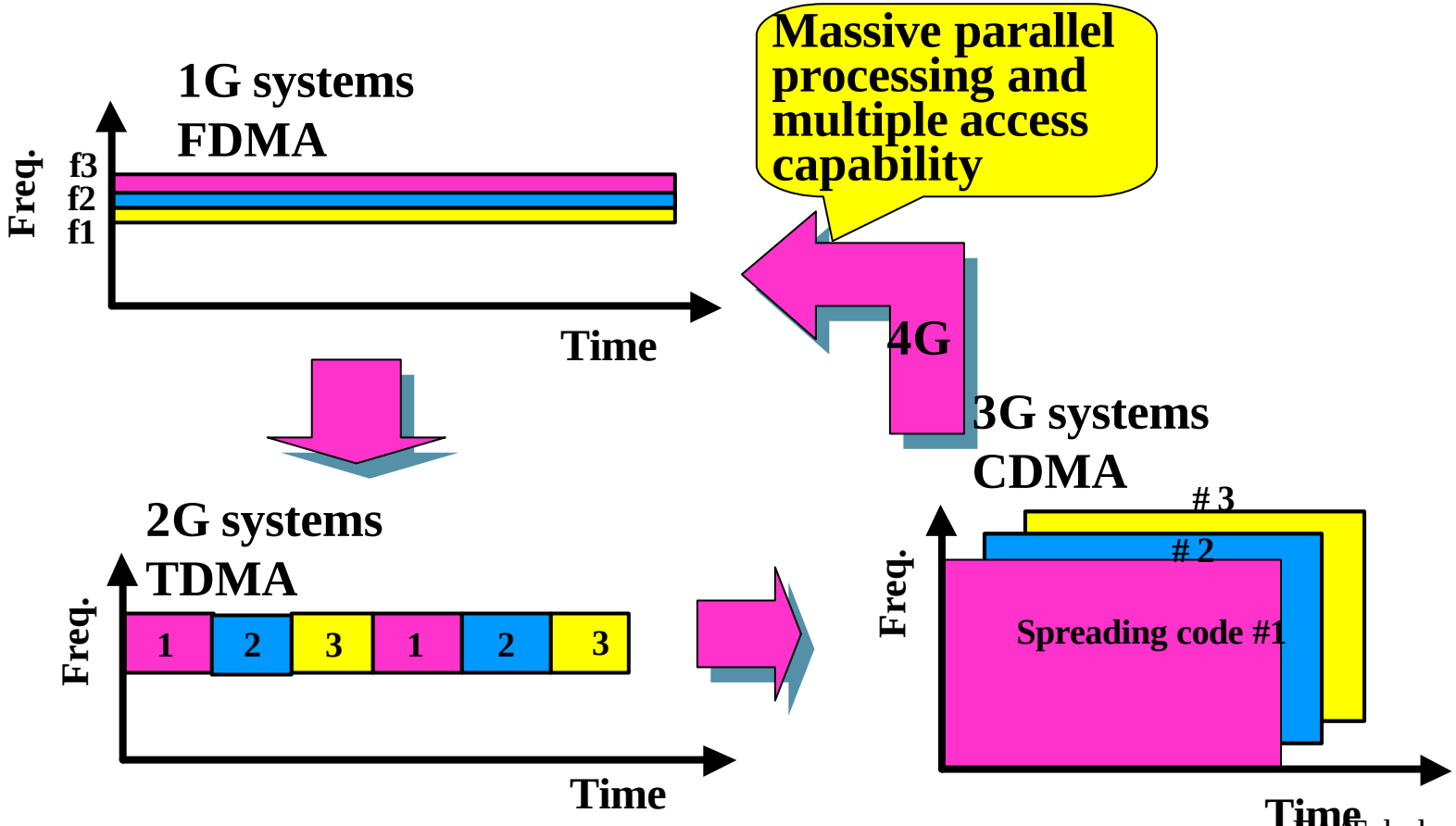
Transfer Function of Wireless Channel

- Frequency transfer function is distorted due to multiple propagation paths having different time delays.
- However, when observed over narrow bandwidth, it can still be seen as constant.



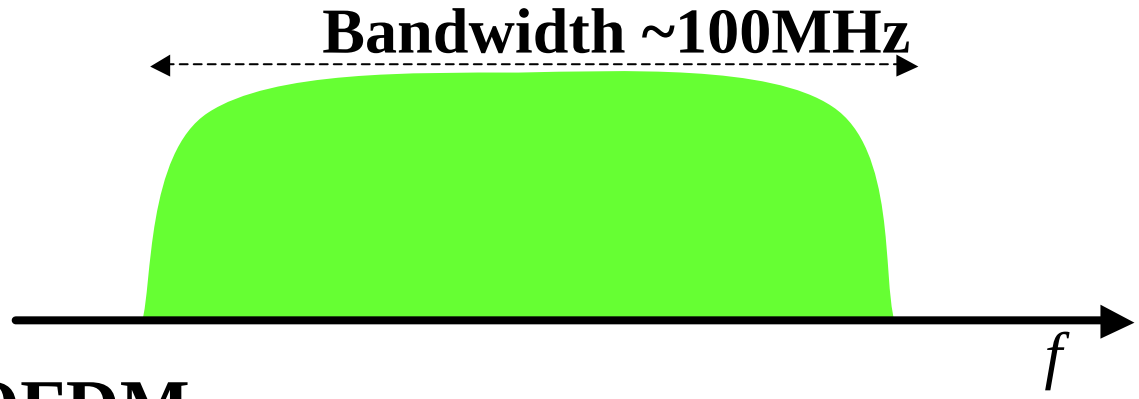
Why Not Revisiting To Frequency Domain Processing ?

- Incorporation of massive parallel processing into frequency domain processing: OFDM

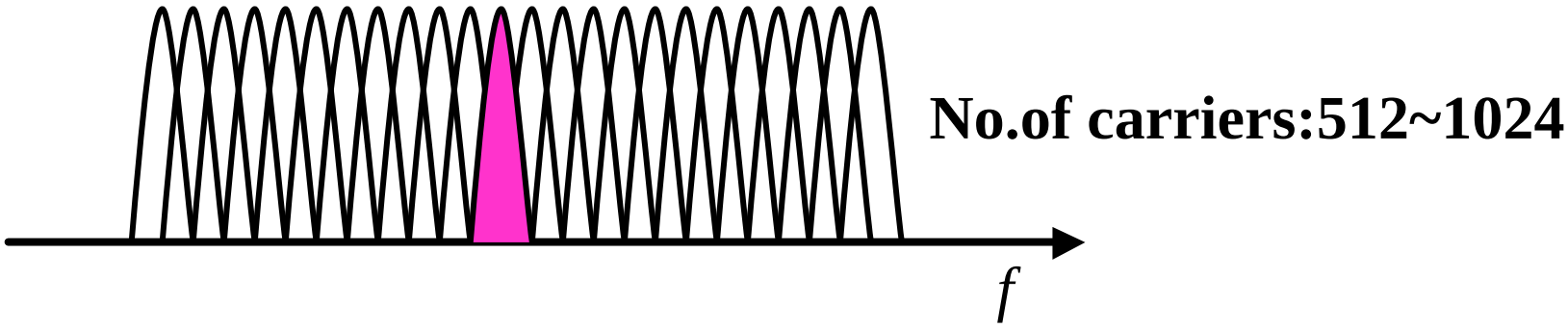


Spectra of DS and OFDM Signals

- **DS**



- **OFDM**



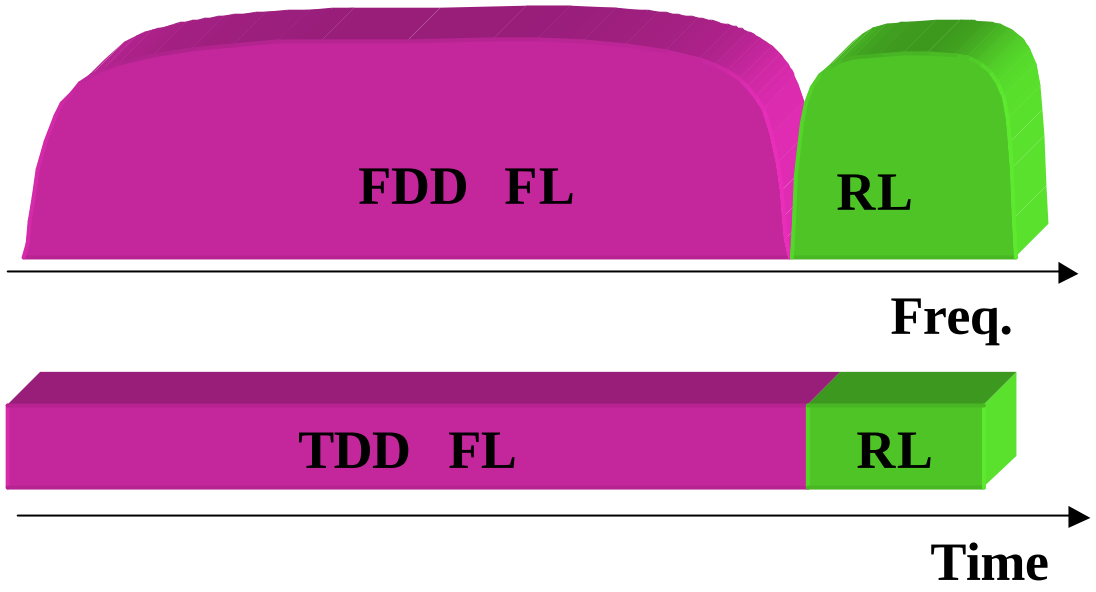
Comparison of TDMA, CDMA, and OFDM

- Limitations
  - TDMA : too long delays for equalization
  - DS-CDMA : too weak paths for Rake combining
  - OFDM : no multipath diversity, large peak-to-average power ratio

Access	Fading	Multipath diversity	Site diversity	Peak power
TDMA	Freq. selective	Equalizer	Hard handoff	>1
DS-CDMA		Rake	Soft handoff	1
OFDM	Freq. Nonselect.	NA		>>1

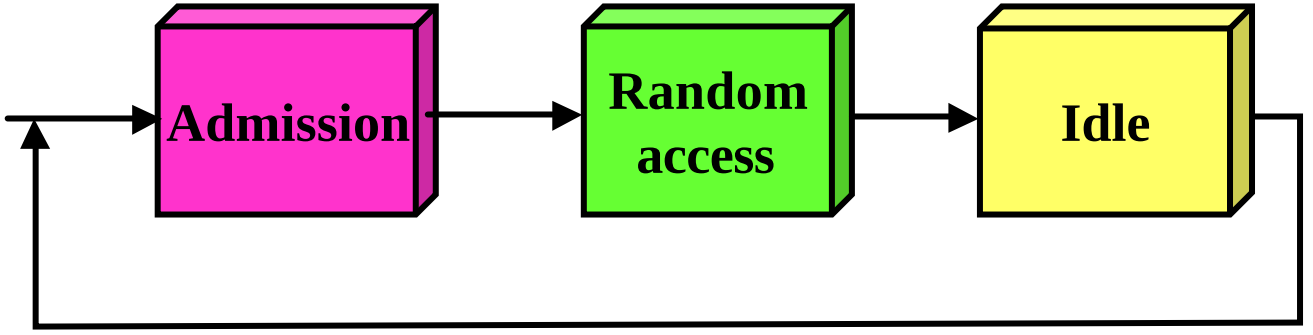
Duplex Scheme

- Significantly asymmetric traffic between FL and RL
- TDD vs FDD. TDD may be suitable because of higher flexibility of bandwidth allocation



Random Access on RL

- Random access
  - Coded random access
  - Reservation ALOHA or its hybrid with others
  - Efficient collision resolution
- Admission control
  - Allocation of a channel of e.g. OFDM-CDMA
  - Sharing of a channel with other users for random access



Conclusion

- **Our society of 21st century will become a multimedia society supported by Internet and mobile wireless technologies in 10 years.**
- **Mobile communications systems will take a role of present fixed telephone networks soon and mobile terminals will become a necessity to daily life. However, most of mobile communications traffic will be Internet-related and voice conversation will be a small part.**
- **On the other hand, fixed telephone network will evolve to information KIOSK at homes and offices, connected to high speed Internet via metallic cables using xDSLs and optic fiber cables.**
- **4G mobile communications systems may appear around 2010, supported by Megabit wireless technologies.**