Ultra High-speed Radio Communication Systems and Their Applications - Current Status and Challenges -

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Outline

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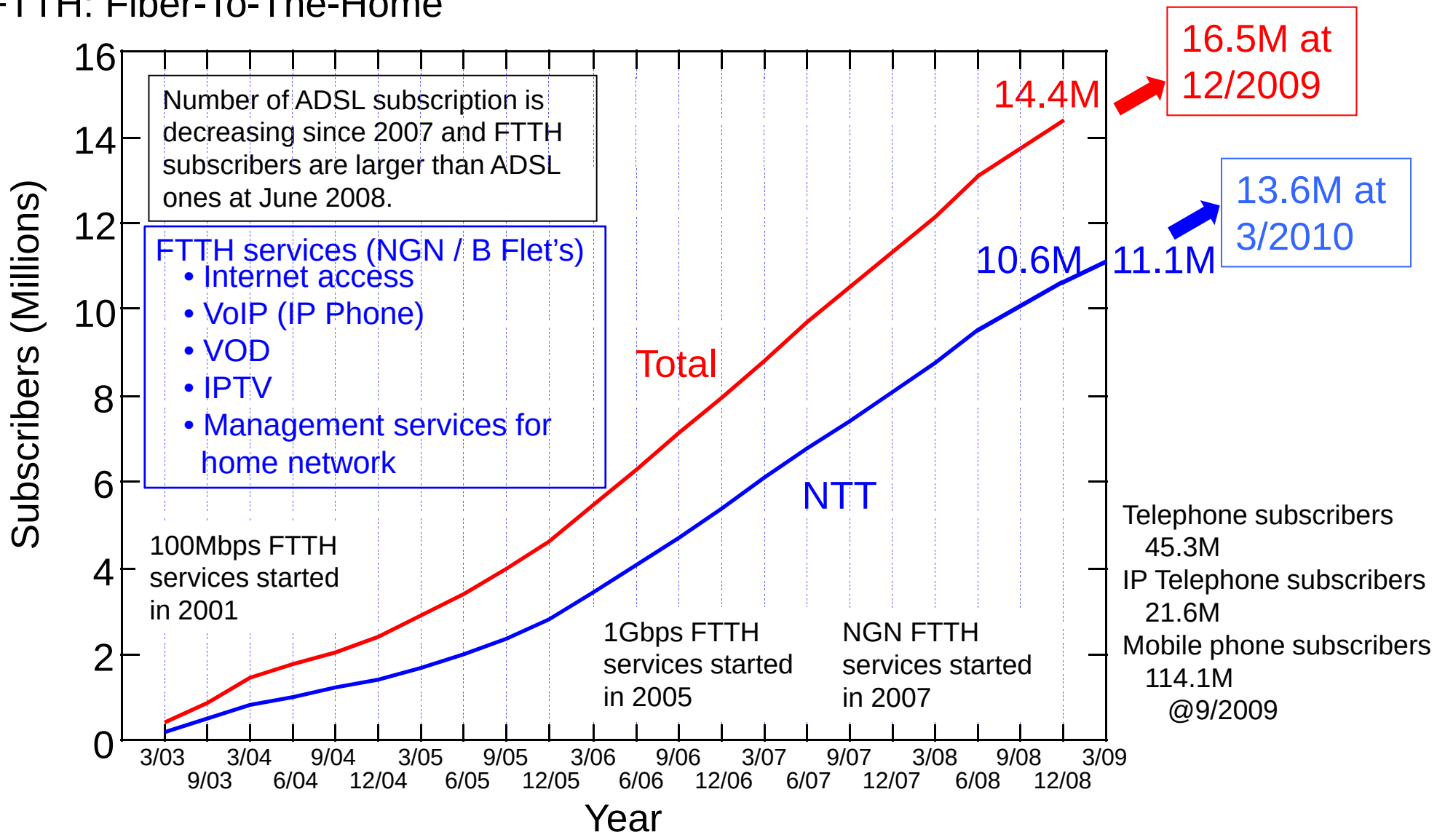
- Introduction
- Standardization activities
- Activities of NTT Network Innovation Labs.
  - Scenario of 60 GHz wireless applications
  - Miniaturized 60 GHz Wireless Module
  - 4K video wireless transmission system
  - Short-range MIMO
- Conclusion

Trends in the total FTTH subscribers in Japan

FTTH: Fiber-To-The-Home



Advantages of ultra high-speed wireless transmission 1

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Expected transfer speed of multimedia contents

Application	Media	Size	Transfer speed (sec)		
			100Mbit/s	1Gbit/s	2.5Gbit/s
Movie	DVD	4.7GB	376	37.6	15.0
Music	CD	650MB	52	5.2	2.08
	MP3	65MB	5.2	0.52	0.208
Software / Data	DVD-ROM	4.7GB	376	37.6	15.0
	CD-ROM	650MB	52	5.2	2.08
Photo	4M pixel	1.7MB	0.136	0.0136	0.00544
News paper	Text	1MB	0.08	0.008	0.0032

Advantages of ultra high-speed wireless transmission 2

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Required data rate of uncompressed HD video

Video standard	Pixel X	Pixel Y	Frame rate (fps)	Interlace=0.5 Progressive=1	Bus format (bit)	2D movie Data rate (Gbit/s)	3D movie Data rate (Gbit/s)
1080/60i	1920	1080	60	0.5	24	**1.49**	**2.99**
	1920	1080	60	0.5	36	**2.24**	**4.48**
	1920	1080	60	0.5	48	2.99	5.97
1080/60p	1920	1080	60	1	24	**2.99**	5.97
	1920	1080	60	1	36	**4.48**	8.96
	1920	1080	60	1	48	5.97	11.94
2160/60p (4Kx2K)	3840	2160	60	1	24	11.94	23.89
	3840	2160	60	1	36	17.92	35.83
	3840	2160	60	1	48	23.89	47.78
2160/60p (Digital cinema)	4096	2160	60	1	24	12.74	25.48
	4096	2160	60	1	36	19.11	38.22
	4096	2160	60	1	48	25.48	50.96

Red color: already production

Data rate does not include overhead data

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Standardization activities and Consortiums

- 60-GHz band
  - US 57GHz - 64GHz
  - EU 59GHz - 66GHz
  - Japan 59GHz - 66GHz (unlicensed band)
    57GHz - 59GHz (Licensed band)

➡ Considering to re-open as unlicensed band

- Standardization activities
  - -IEEE 802.15.3c
    approved the 1st edition in Oct. 2009: IEEE Std 802.15.3c-2009
  - -IEEE 802.11ad
    is discussing
  - -ECMA TC-48
    approved the 1st edition in Dec. 2008: ECMA-387
- Consortiums
  - -Wireless HD
    released WirelessHD 1.0 specification on 7th Oct. 2007: already produced
  - -CoMPA
    was leading IEEE 802.15.3c standardization
  - -WiGig
    is leading IEEE 802.11ad standardization

Standardization activities and Consortiums 2

- 2.4-GHz band
- 5-GHz band

- Standardization activities
  - -IEEE 802.11n
    - approved the 1st edition in Oct. 2009: IEEE Std 802.11n-2009, already produced
  - -IEEE 802.11ac
    - is discussing

- Consortiums
  - -WHDI (Wireless Home Digital Interface)
    - released WHDI 1.0 specification on 8th Dec. 2009
    - 5-GHz band
  - -There are some consortiums/groups in IEEE 802.11ac

Comparison of main standardizations

Standard	IEEE802.11n	IEEE802.15.3	IEEE802.11ac (VHT)	IEEE802.11ad (VHT)	ECMA-TC48	Wireless HD	WiGig	WHDI
Data rate	>100 Mbps	>5Gbps	>1Gbps	>1Gbps	6.35 Gbps	Up to 4Gbps	Up to 7Gbps	Up to 3Gbps
Transmission method	MIMO-OFDM	SC/OFDM	(MU-MIMO)	-	SC/OFDM	OFDM	-	
Channel BW	20/40 MHz	2.16 GHz	40/80/160 MHz	-	2.16 GHz	1.76 GHz	-	40MHz
Center frequency	2.4GHz/ 5GHz	60GHz	<6GHz	60GHz	60GHz	60GHz	60GHz	5GHz
Coverage	30m	10m			10m	10m	10m	30m
Beam forming		X			X	X	X	
Completion date	Oct., 2009.	Oct., 2009	2012	2012	Dec., 2008	Oct., 2007	Q1, 2010	Dec., 2009

Production

Production

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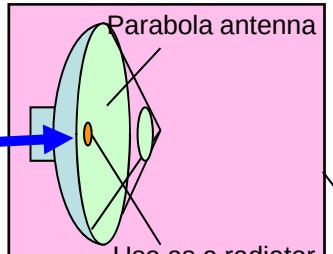
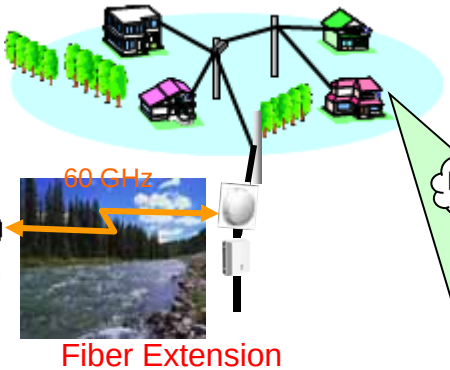
Scenario of 60 GHz Wireless Applications

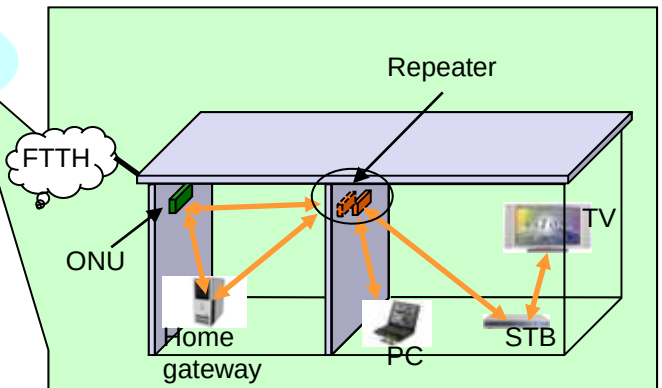
Compact size
Low power
Low cost
PtoMP operation

Compact wireless module image

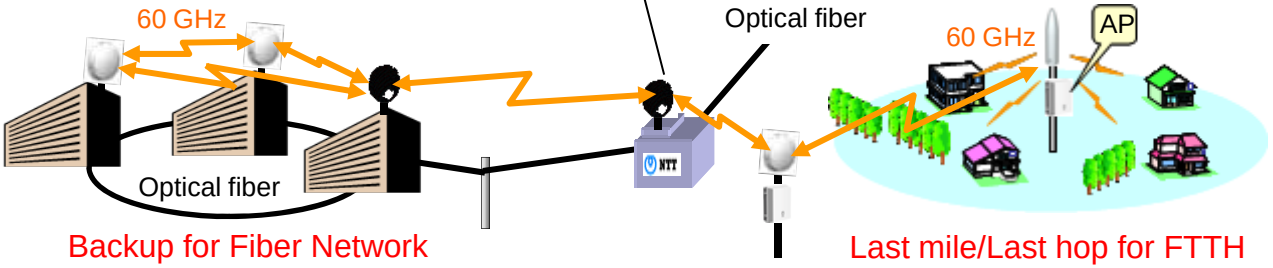




Fiber Extension



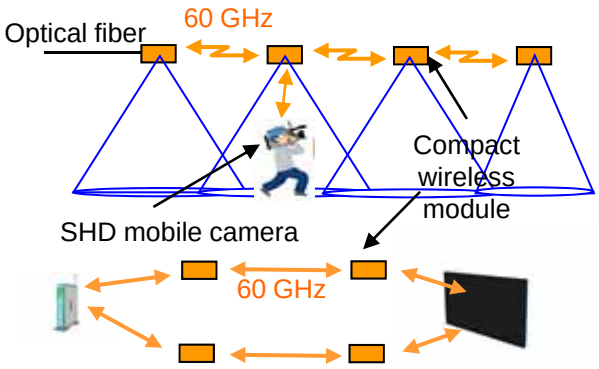
High-speed Home network



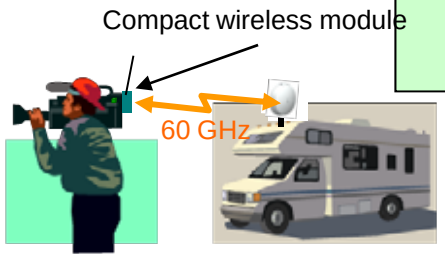
Backup for Fiber Network

Last mile/Last hop for FTTH

High-speed Data Download to Mobile Terminal



Ad-hoc Network



SHD (4K) Mobile Camera/Video Transmission

Application image of home network

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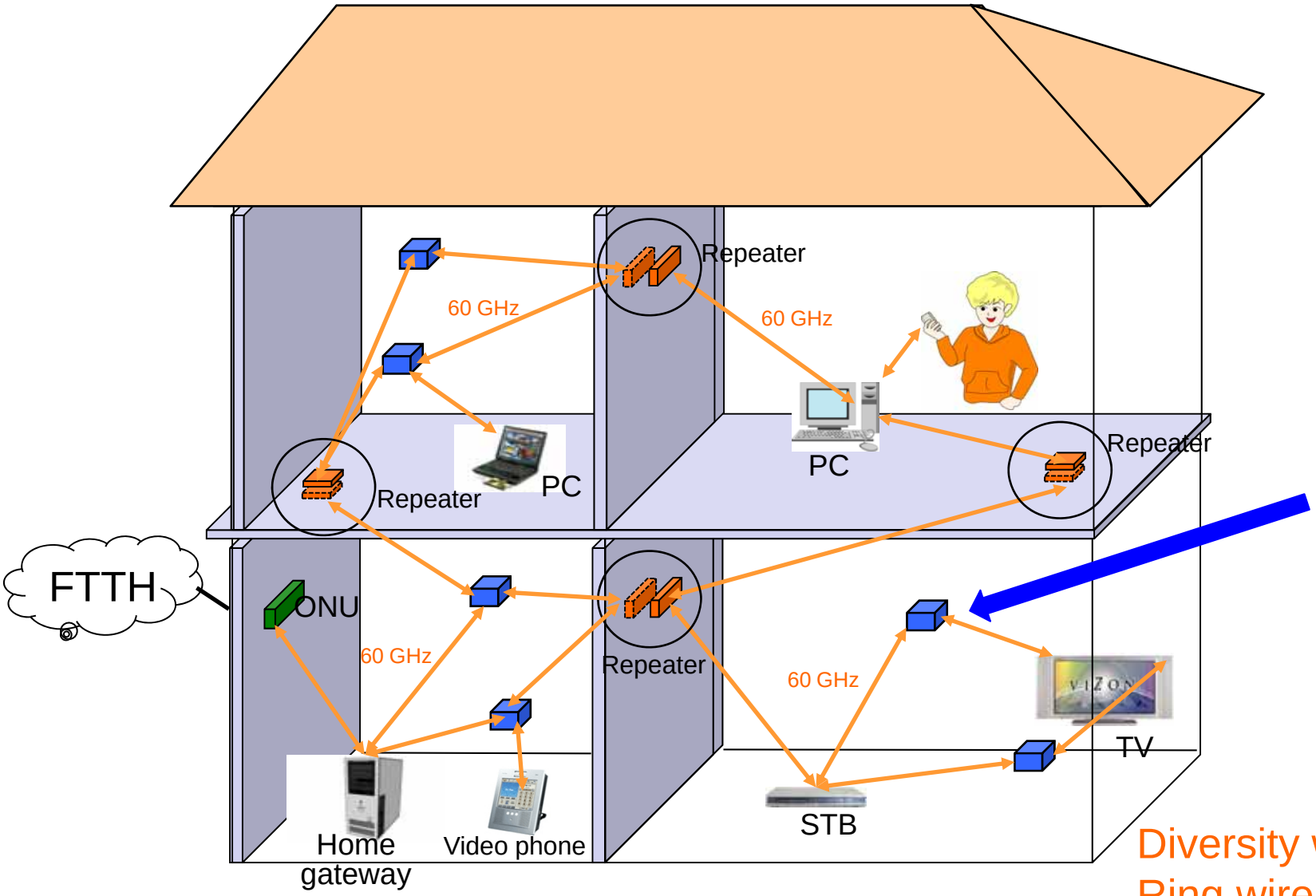
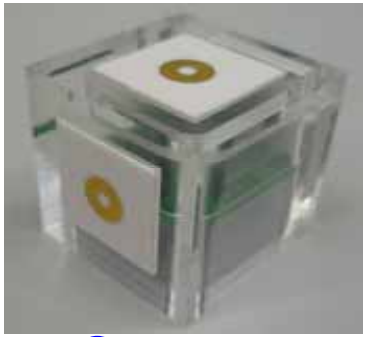


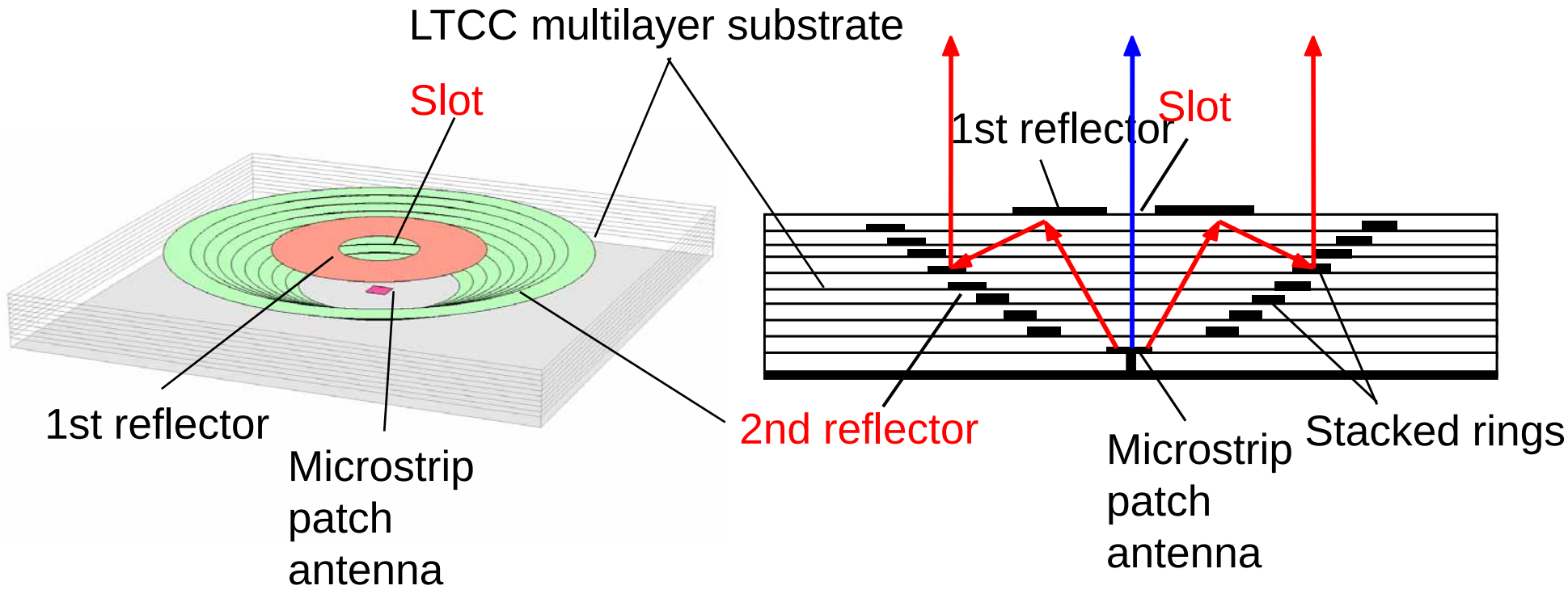


Compact wireless module

Diversity wireless link
Ring wireless link

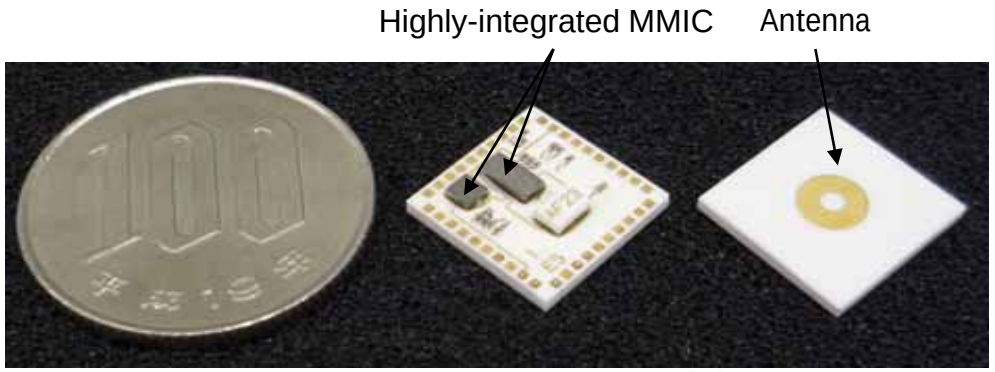
Miniaturized 60 GHz Wireless Module

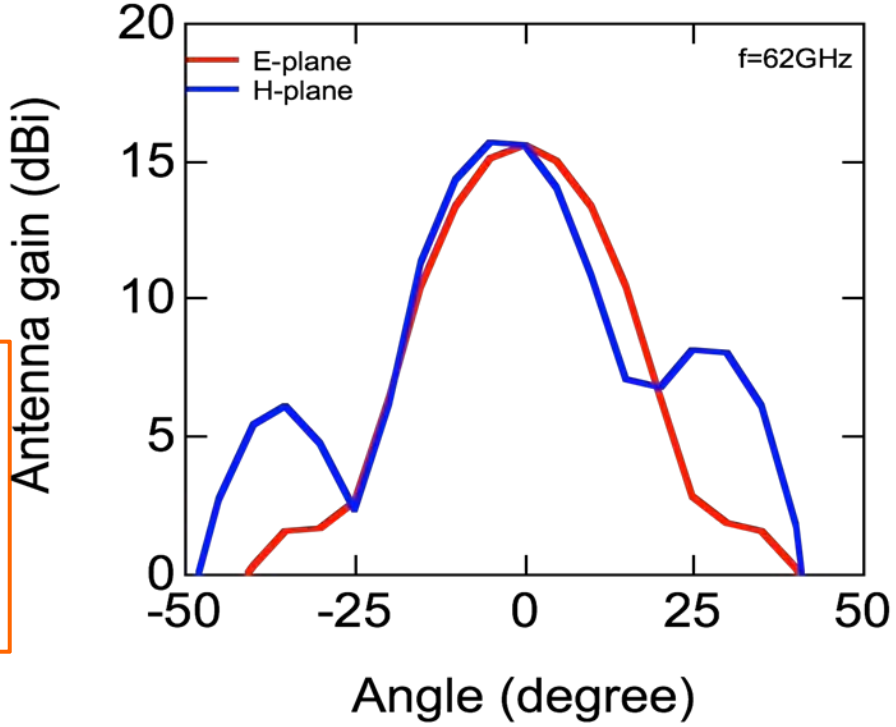
Microstrip Antenna Employing Stacked Ring



Parabola-like performances are expected by using thin ceramic substrate.

Millimeter-wave SiP with High-gain Antenna

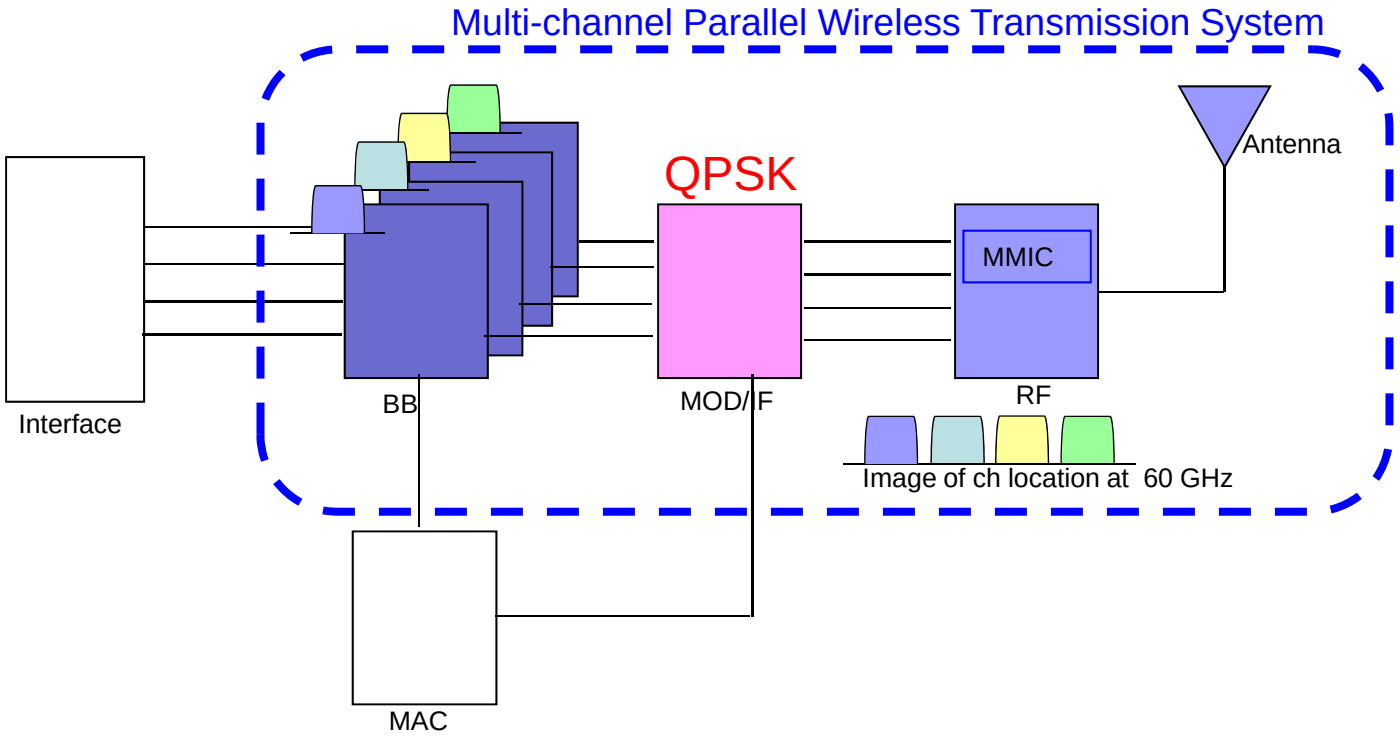


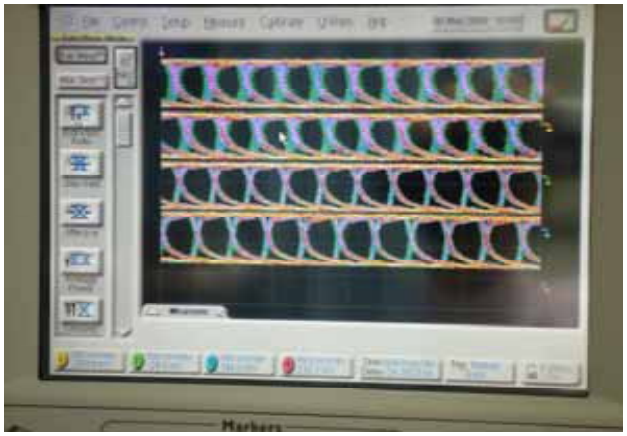


Antenna Gain	16dBi
Bean width	20degrees
SiP size	12mm×12mm×2mm
Operation frequencies	57GHz-66GHz
IF bandwidth	DC-12GHz

4K Video Wireless Transmission System

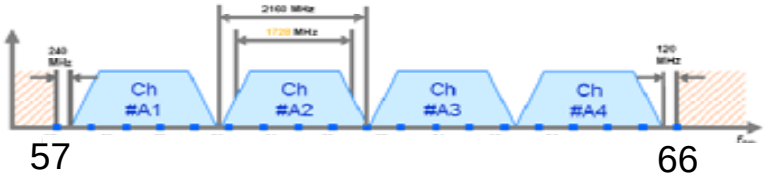
Multi-channel Parallel Wireless Transmission System





Eye-patterns of multi-channel parallel wireless transmission

A1	57.240	58.320	59.400	1728	0.25
A2	59.400	60.480	61.560	1728	0.25
A3	61.560	62.640	63.720	1728	0.25
A4	63.720	64.800	65.880	1728	0.25



Channel plan is based on IEEE 802.15.3c.
Modulation scheme is QPSK.
Modulation index is 0.5

4K Video Wireless Transmission System

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4K video server

HD-SDI x4

HD-SDI to DVI converter

BB

MOD/IF

RF

Antenna

60GHz

4K video

Antenna

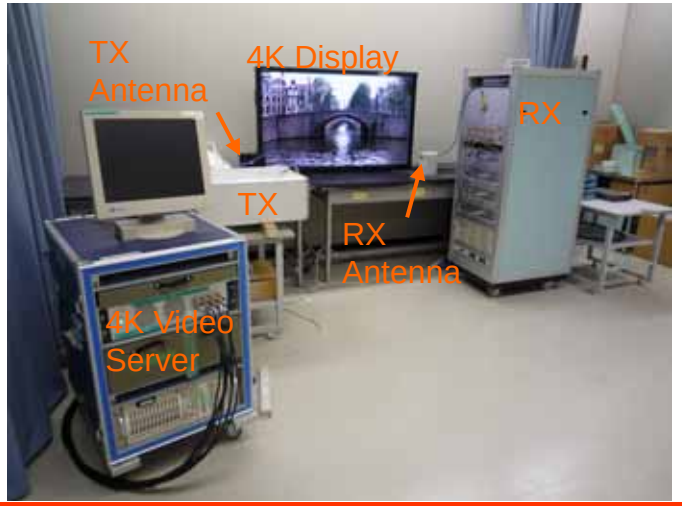
RF

IF/DEM

BB

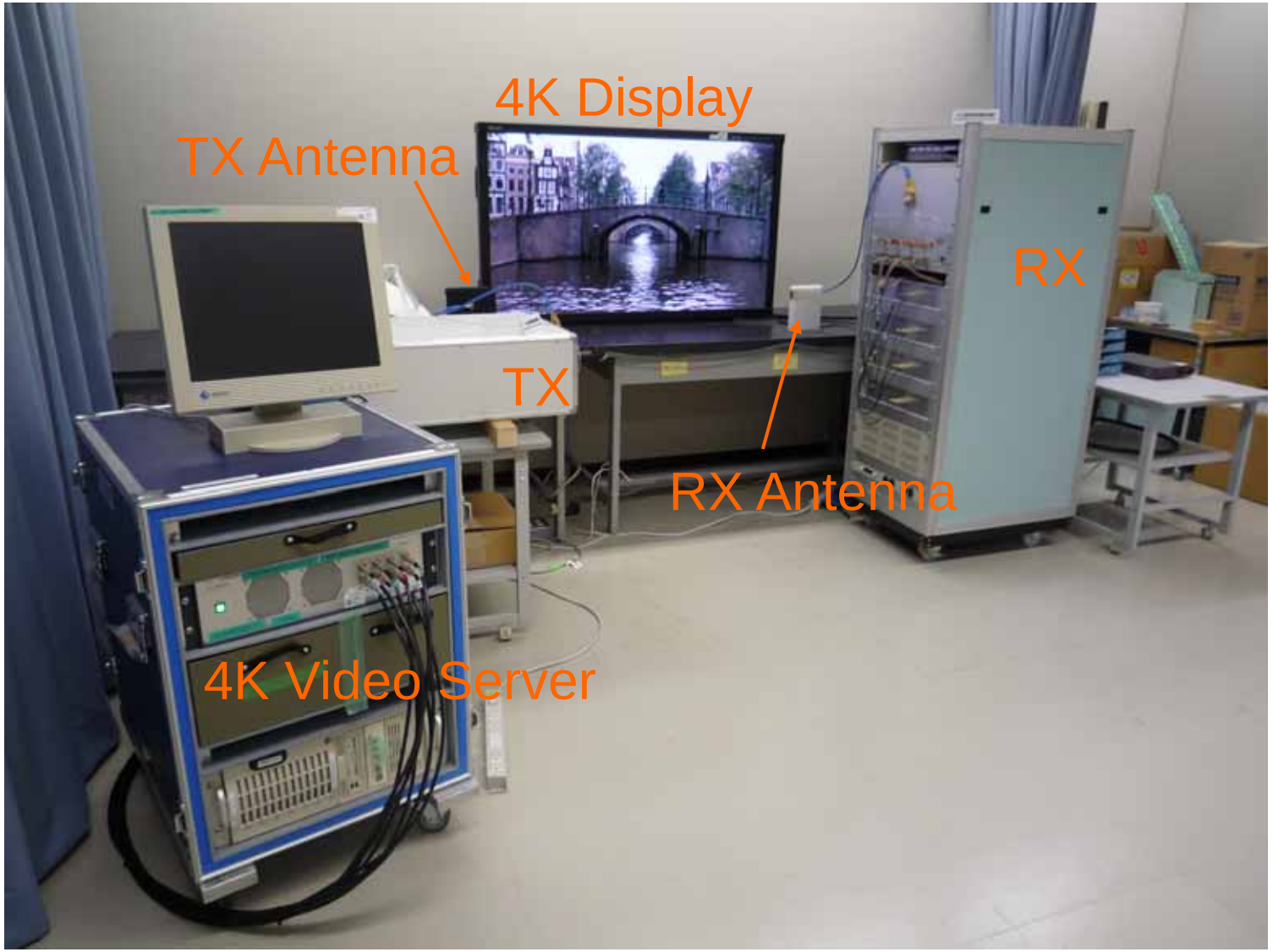
HDMI to HDSDI converter

HD-SDI x4



4K monitor

4K Video Wireless Transmission System 2

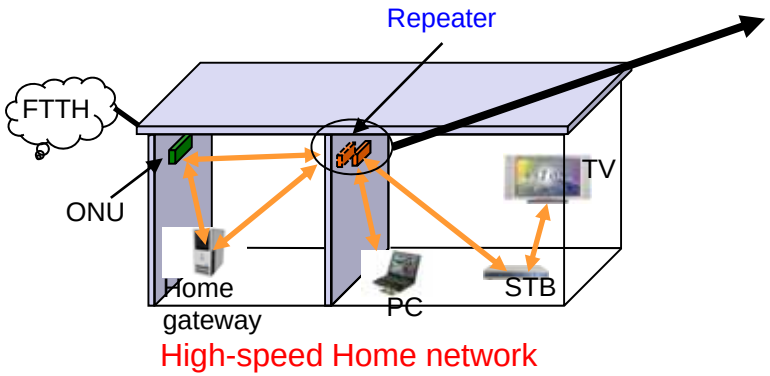


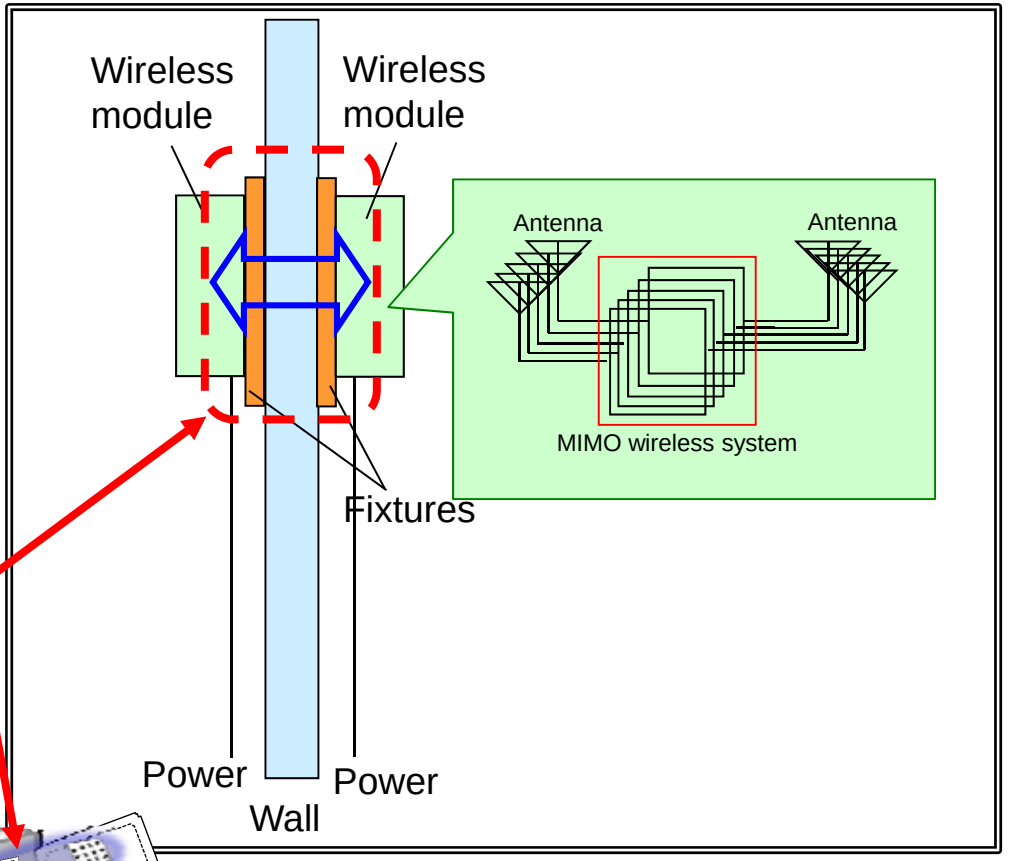
Short-range MIMO Transmission

- Wireless Repeater (Through-wall) application (MW)
- Date transfer application (MMW)

Application Image

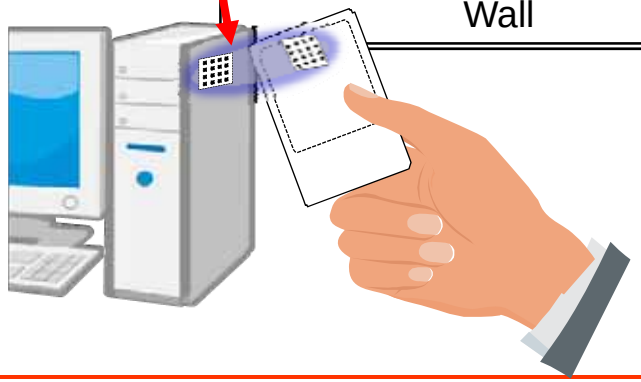
- Wireless Repeater





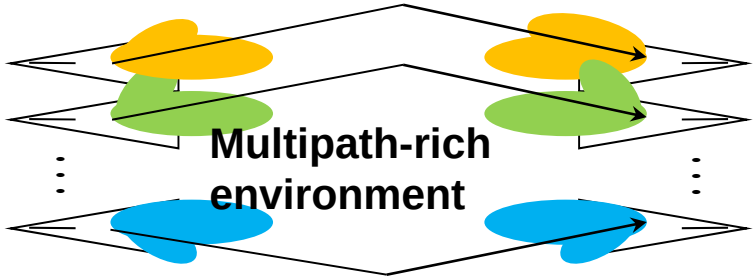
MIMO transmission
(Short-range MIMO communication)

- Data Transfer



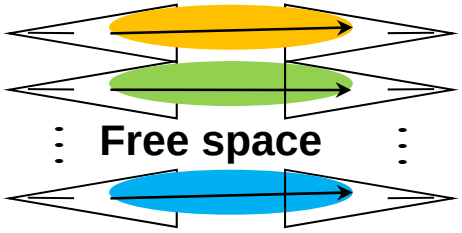
Ultra-high-speed transmission technique

Normal MIMO



- There are multiple streams of signals even in finite element spacing at multipath-rich environment.
- With few multi-path waves, it is difficult to transmit multiple streams.

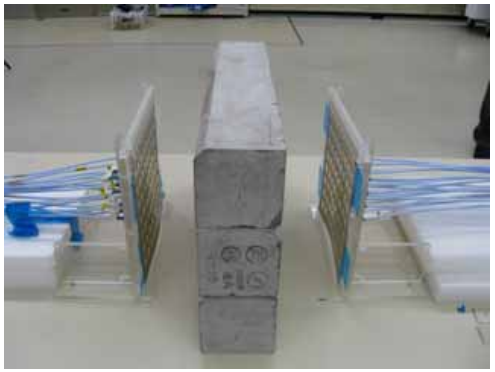
Short-range MIMO

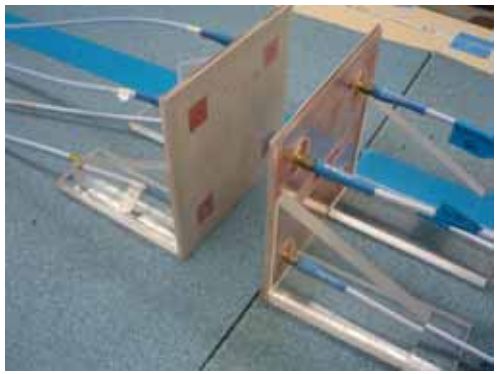


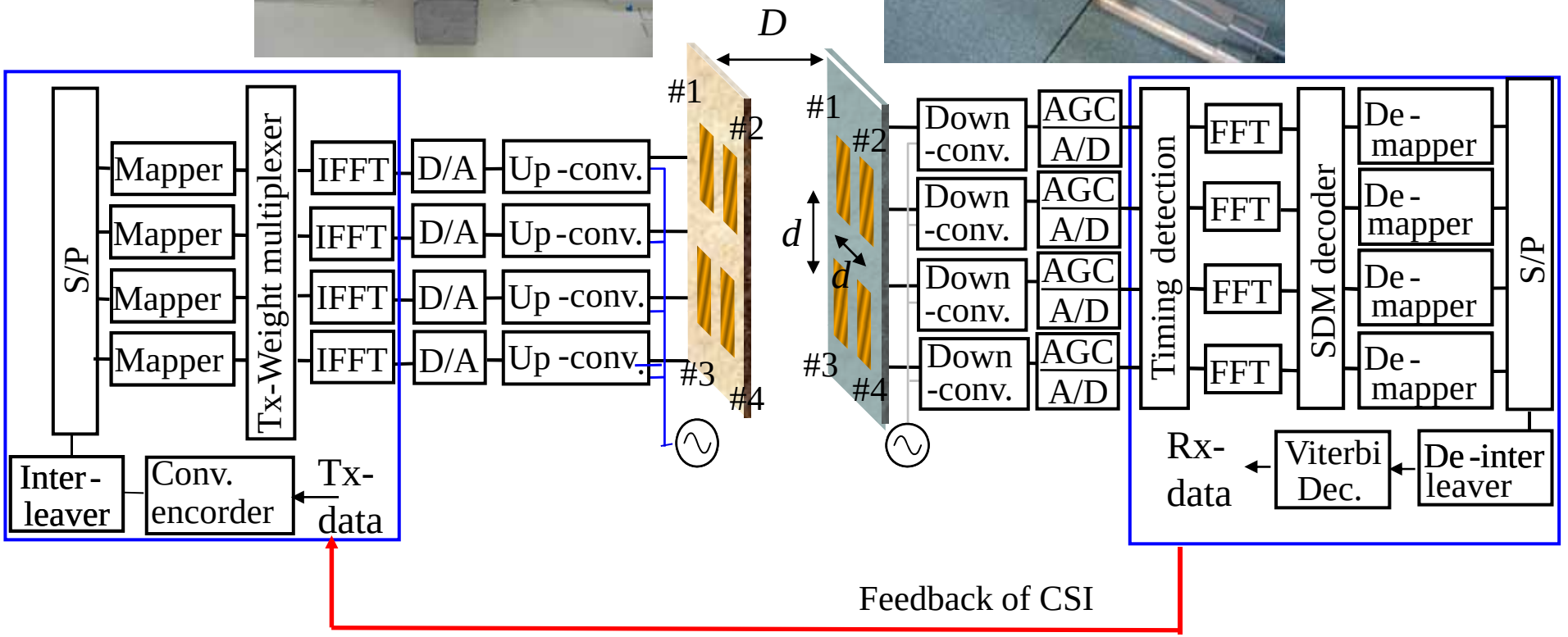
- Transmission distance is short compared with the aperture size.
- Transmission lines are formed in parallel **without multipath.**
- Both low spatial correlation and high SNR can be achieved with small interelement spacing.

Short-range MIMO is suitable for short-range, high-speed transmission.

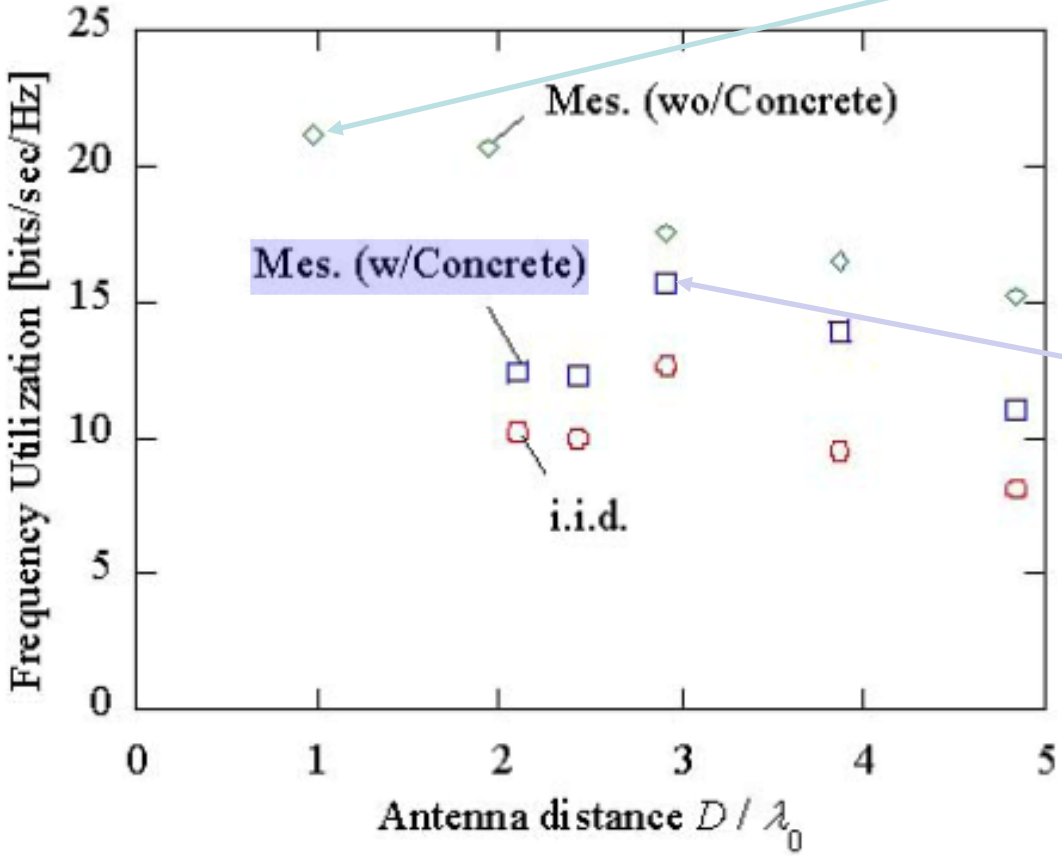
MIMO Test System







Frequency Utilization versus Antenna Distance



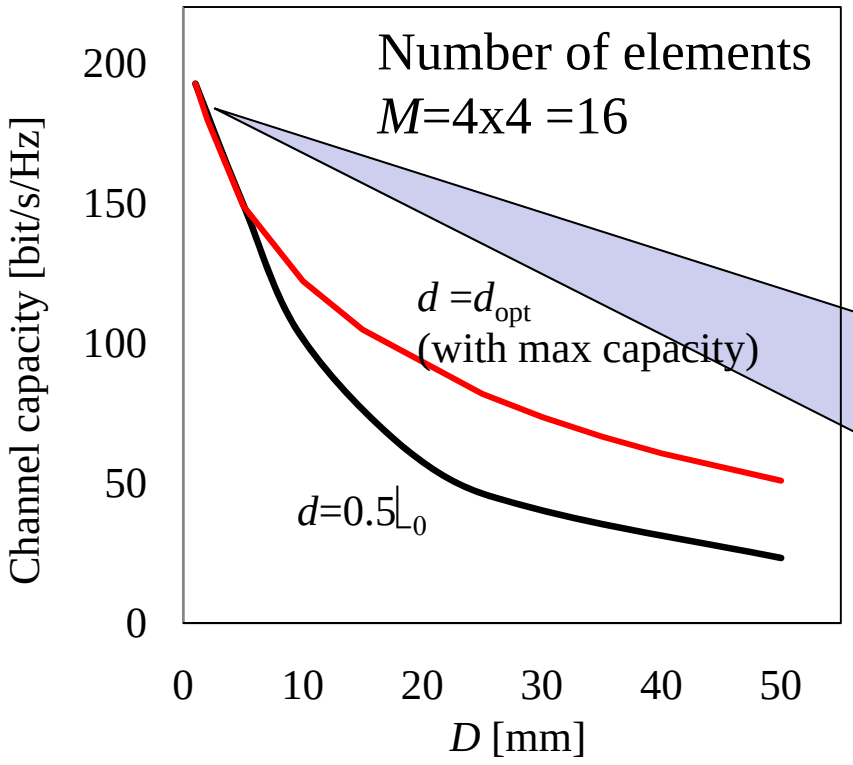
- Frequency utilization of over 20 bits/s/Hz can be achieved: 800Mbps/1.6Gbps transmission can be realized in the bandwidth of 40/80 MHz.

- Frequency utilization of over 15 bits/s/Hz can be achieved: 600Mbps/1.2Gbps transmission can be realized in the bandwidth of 40/80 MHz.

IEEE802.11n:40MHz
IEEE802.11ac:80MHz

- The measured results indicate higher frequency utilization rates than the i.i.d. channel.

Evaluation of Millimeter-wave Short-range MIMO System



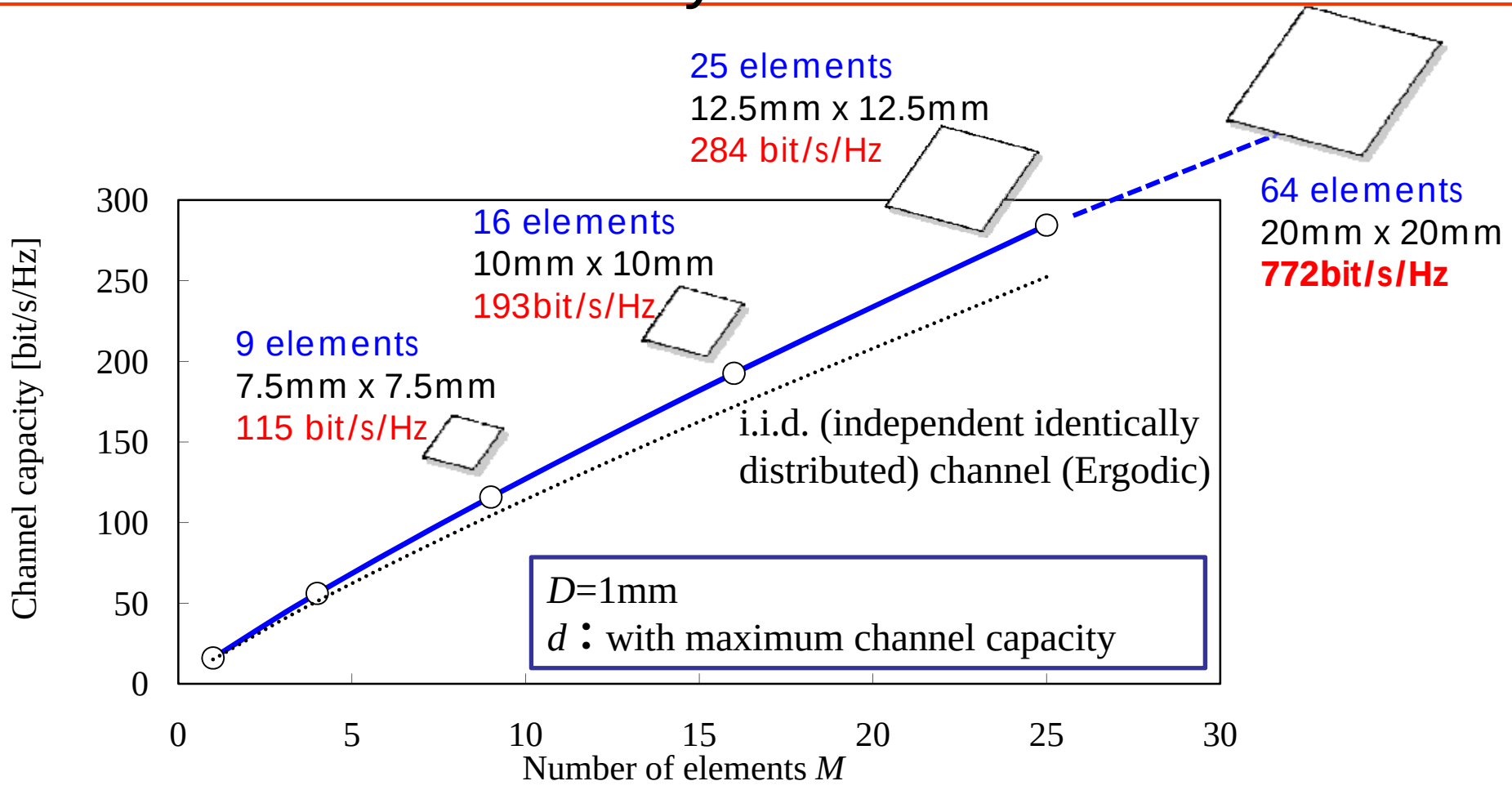
Higher channel capacity is available by employing the optimum interelement spacing

When *D (distance between systems)* = 1mm,
Channel capacity = 193bit/s/Hz

In bit-rate terms, for a bandwidth of 2.16 GHz
= 193bit/s/Hz x 2.16GHz
= 417 Gbit/s

Channel capacity of several hundred Gbit/s is attainable using small (20 mm x 20 mm) antenna arrays

Evaluation of Millimeter-wave Short-range MIMO System



■Channel capacity increases almost in proportion to *M*
■*M* can be increased to 64 for an antenna size of 20 mm x 20 mm
■The channel capacity should be over 700 bit/s/Hz,
(In bitrate for a bandwidth of 2.16 GHz, it is over 1600 Gbit/s)

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Conclusion

- Standard activities of ultra high-speed wireless systems
- Scenario of 60 GHz wireless applications
- 4K video wireless transmission system
- Short-range MIMO system and applications

References

1. 802.15.3cWPANTaskGroup,http://www.ieee802.org/15/pub/TG3c.html
2. J. M. Gilbert, C. H. Doan, S. Emami, C. B. Shung, ”A 4-Gbps uncompressed wireless HD A/V transceiver chipset,” Hot Chips 19, 2008.
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5. T. Seki, K. Nishimori, N. Honma, and K. Nishikawa, "High speed parallel data transmission system for near field wireless relay system," IEICE Technical report Ap2008-124, Nov., 2008.
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9. N. Honma, K. Nishimori, T. Seki, and M. Mizoguchi, “Short Range MIMO Communication,” 3rd European Conference on Antenna and Propagation (EuCAP), pp. 1763-1767, Mar. 2009.
10. T. Seki, K. Nishimori, K. Hiraga, and K. Nishikawa, “Experimental Evaluation of High-speed Parallel Data Transmission Technology for Wireless Repeater System,” 2010 IEEE Radio and Wireless Symposium, TUP-19, Jan. 2010.
11. K. Hiraga, T. Seki, K. Nishimori, K. Nishikawa, and K. Uehara, “Ultra-High-Speed Transmission over Millimeter-Wave using Microstrip Antenna Array,” 2010 IEEE Radio and Wireless Symposium, TH2B-5, Jan. 2010.

IEEE 802.11ac

IEEE802.11-VHT below 6GHz (IEEE802.11ac)

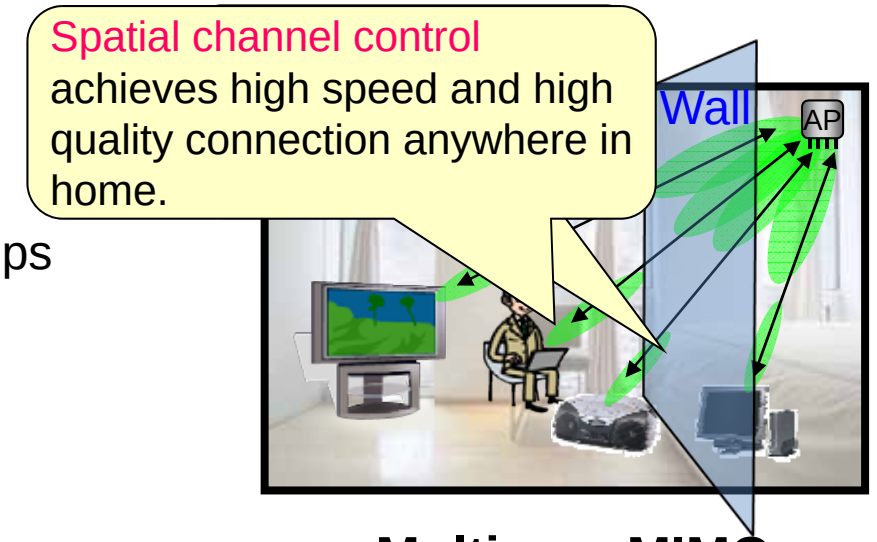
■Aiming at higher throughput, **a TG for the 6-GHz frequency band or below**, TGac (established in September 2008), and another TG for the 60-GHz frequency band, TGad (established in December 2008), are working to complete standardization by 2012.

Key features

- MAC-SAP System Throughput > 1Gbps
- MAC-SAP Throughput for each link > 500Mbps
- Frequency band width：20/40/80MHz
- Center frequency: @5GHz band
- Coexistence with IEEE 802.11a/n

Core technologies

- Spectrum efficient technology: MU-MIMO
- Larger bandwidth: >80MHz bandwidth
- Higher order modulation: 256QAM
- Fast session transfer from 11ad to 11ac



Multiuser MIMO

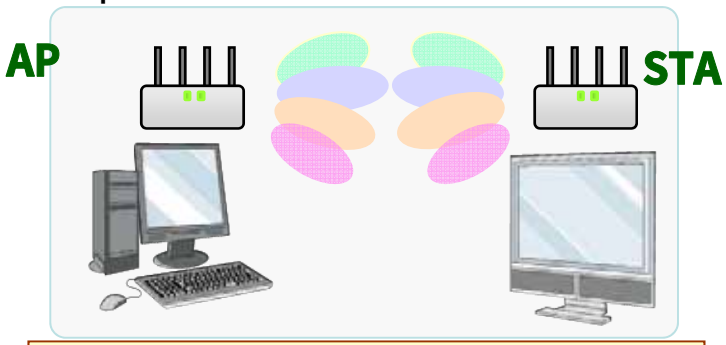
- AP：Access Point
- CSMA/CA：Carrier Sense Multiple Access with Collision Avoidance
- MU-MIMO：Multiuser Multiple-Input-Multiple-Output(MU-MIMO)

Multi user MIMO technology

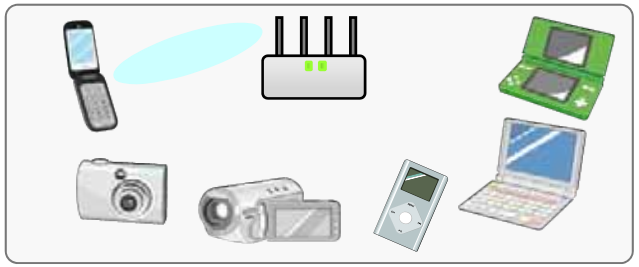
- Precise multiple beam pattern control enables spatial division multiple access (SDMA) that achieves very spectrum efficient transmission.
- MU-MIMO can accommodate various data rate services simultaneously.

■Single user MIMO (SU-MIMO)

Parallel point to point transmission in a multipath environment.



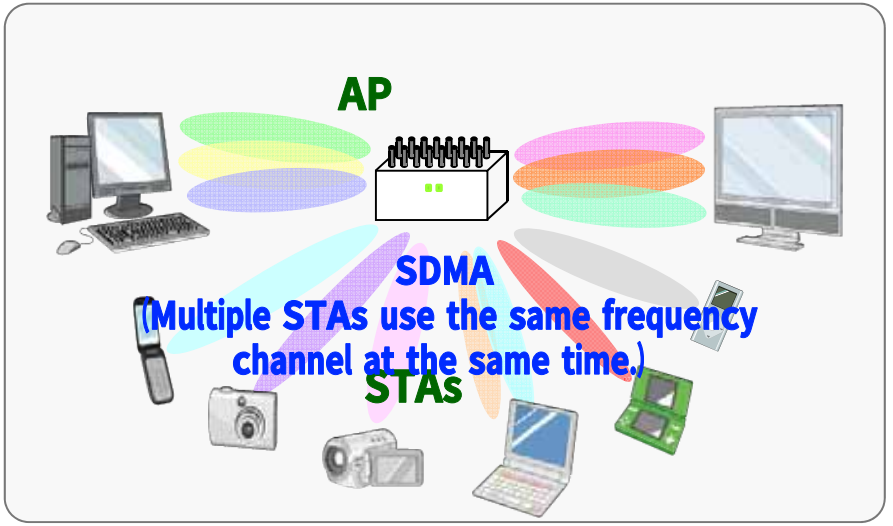
Example: IEEE 802.11n, WiMAX, LTE



Problem: Simple STA with a few antennas degrades total system throughput.

■Multi user MIMO (MU-MIMO)

Precise transmission beamforming enables SDMA.



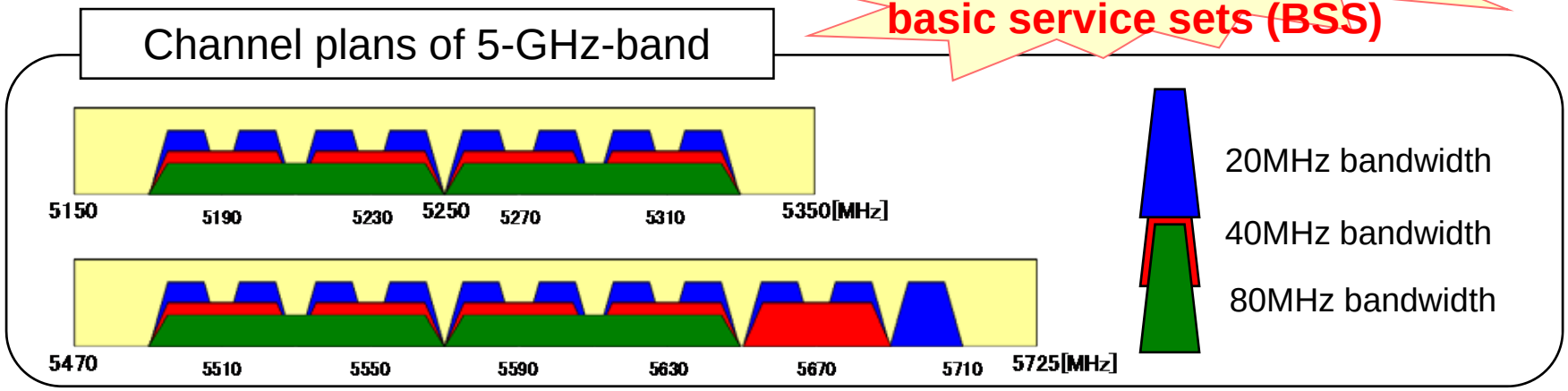
IEEE802.11ac is most likely to use MU-MIMO technology to achieve the 1Gbps system throughput.

Problems in IEEE802.11ac

- Equal to or more than 80MHz is needed to achieve the data rate of 1Gbps.
- Currently, there are 19 frequency channels for 20MHz WLANs in 5GHz band while there are 9 frequency channels for 40MHz WLANs in Japan.
- There would be only 4 frequency channels if 11ac uses bandwidth of 80MHz. It causes severe inter cell interference.

11ac should be carefully designed to satisfy both of the very high throughput and the fairness even in overlapping cell environments.

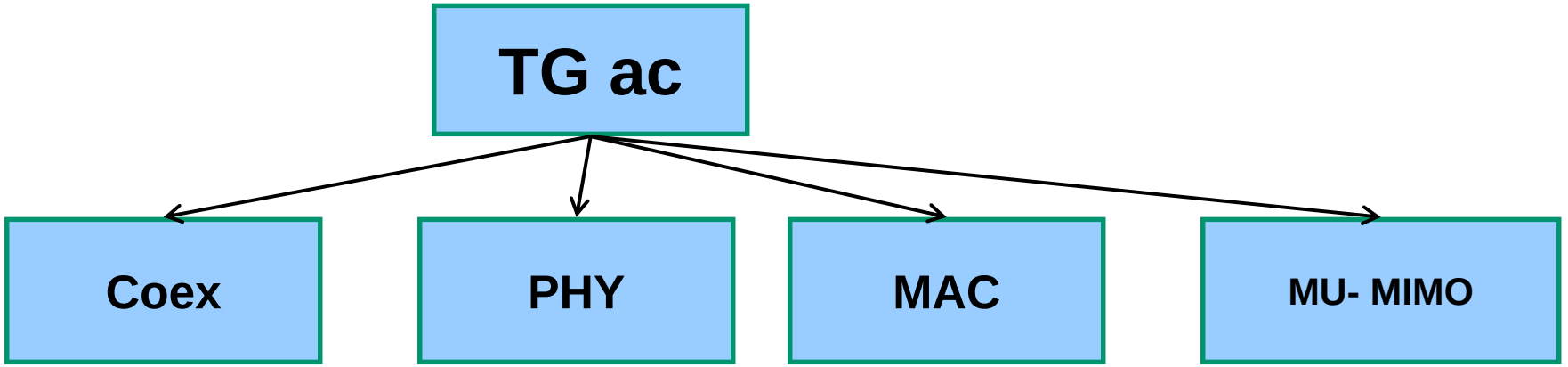
Frequency channel shortage -> Interference among multiple basic service sets (BSS)



Structure of IEEE802.11ac

ref.:IEEE 802.11-09/1175r1

Ad Hoc groups discussion topics



- OBSS Management
- Multi-Channel
  - Non-contiguous channelization
  - MC MAC protocol
  - > 80MHz channel
- Backwards compatibility
- CCA
- Channel access Fairness
- Scanning and channel selection

- Pilots
- Data tones
- Preamble
- Enhanced MCS
- Sounding
- Higher Bandwidth modulation
- Parsing and Interleaving
- Coding, STBC
- Spatial Mapping & Cyclic Delays

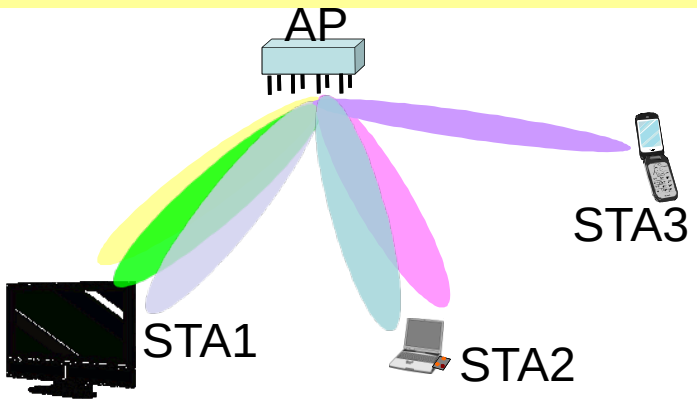
- Power saving
- Capability negotiations
- Frame formats

- Downlink MU-MIMO
- Uplink MU-MIMO
- MU-MIMO parameters (e.g. # of streams, # of clients)
- Training protocols
- ACK protocols
- Reservation/polling protocols

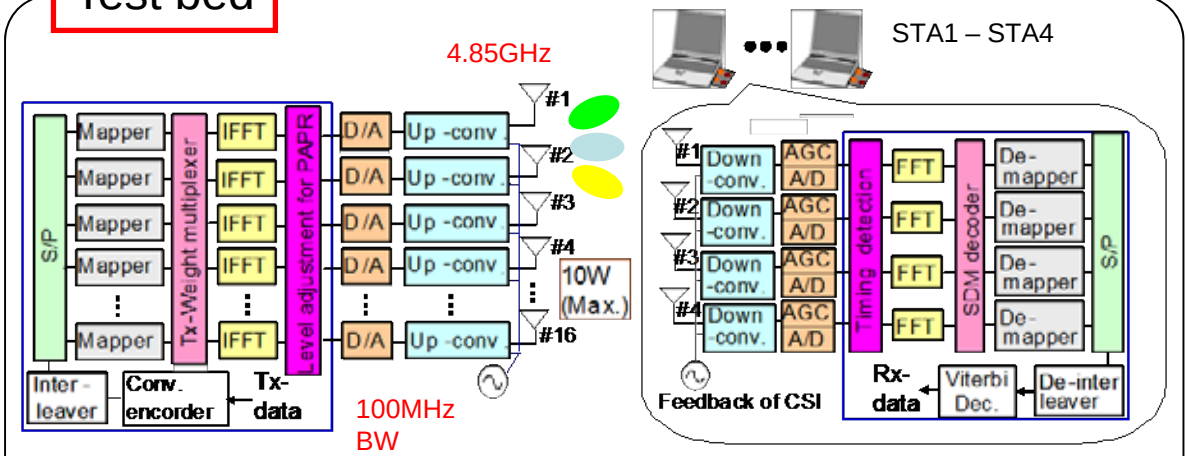
MU-MIMO test bed

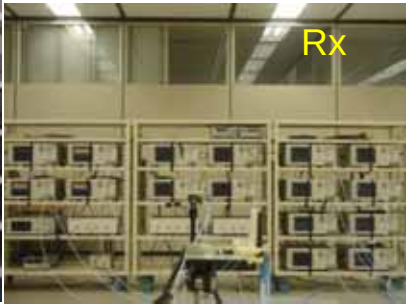
Target scenario

AP accommodates multiple simple STAs which have a small number of antennas.



Test bed

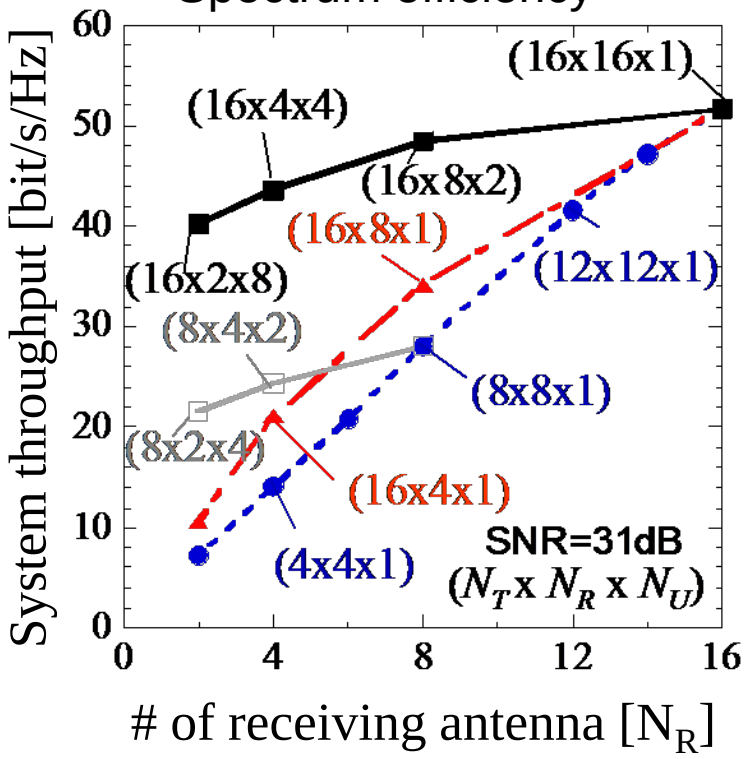




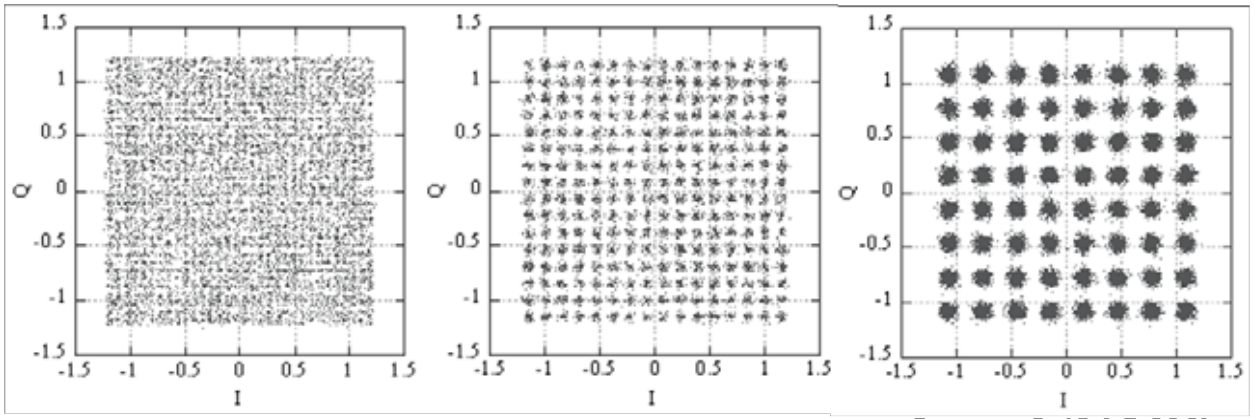
16(Tx)x16(Rx) MU-MIMO-OFDM data transmission

MU-MIMO test results

<Spectrum efficiency>



<Examples of constellation>



It achieves spectrum efficiency of 50bps/Hz (1Gbit/s@20 MHz)