A low power 60GHz CMOS transceiver for WiGig/IEEE 802.11ad, current status and future perspectives

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Panasonic Corporation

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Outline

- Background
- 60GHz CMOS Transceiver with Built-In Self Calibration
  - TX in-band amplitude calibration
  - RX Frequency Domain Equalizer
  - Total Performance
- Future Research for Millimeter Wave
- Conclusion

Background

- Demand for Multi-Gigabit wireless is increasing
- 9GHz bandwidth is allocated as unlicensed band
- Transceiver can be realized in CMOS technology

HD Streaming

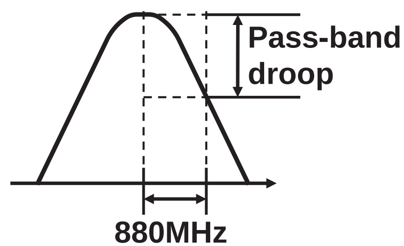
Low Latency
1.5ms (WiGig)
300ms (WiFi)

Fast File Transfer

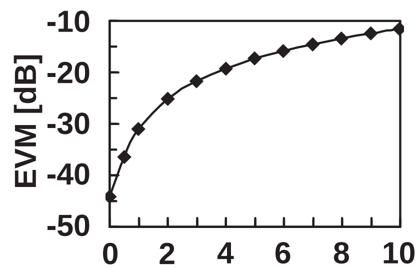
Transfer Time for 2.4GB 30min HD
10sec (WiGig)
1.5min (WiFi)

Challenge of mmW-Transceiver

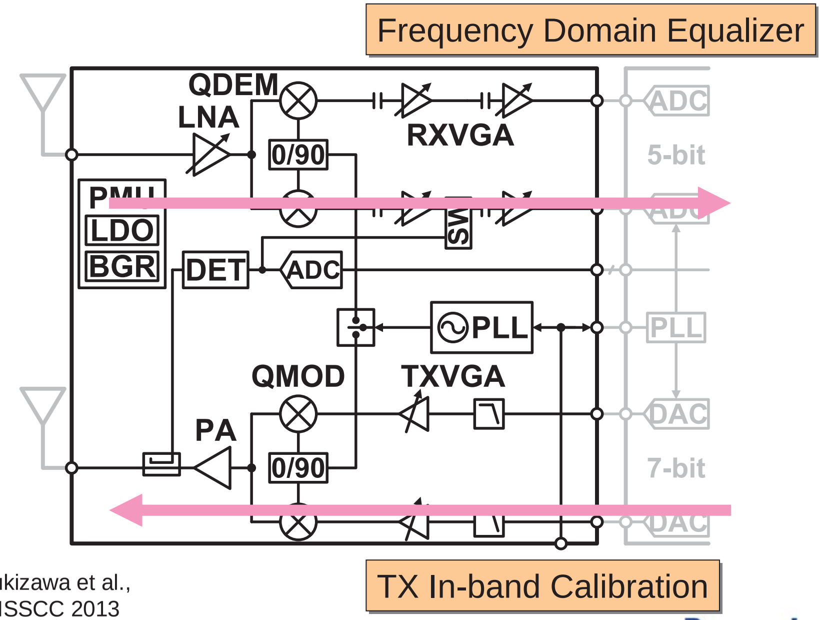
- Low power consumption
  → Direct conversion architecture with single carrier modulation
- Amplitude variation over wide BW (2.16GHz/CH)



Freq. response of analog circuit



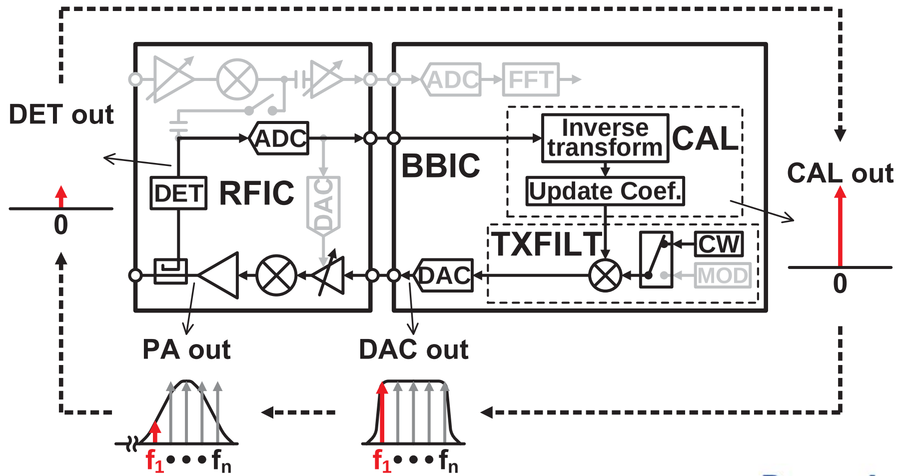
Block Diagram of 60GHz Transceiver



[1] T. Tsukizawa et al., IEEE ISSCC 2013

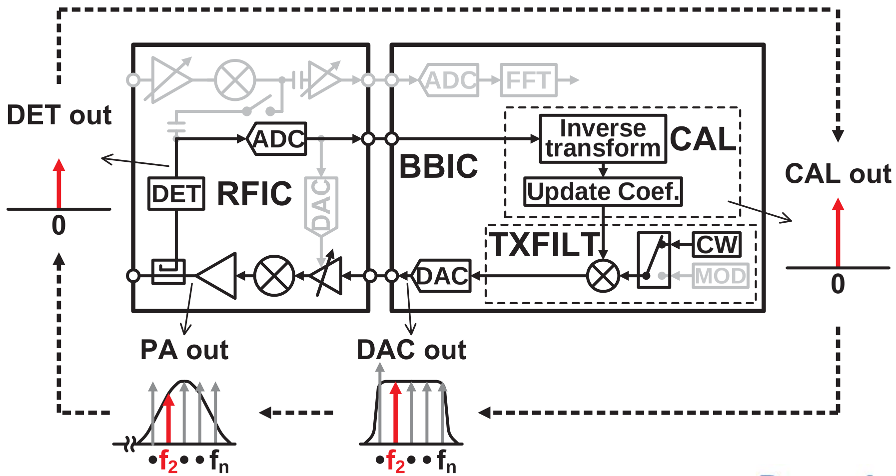
TX In-Band Calibration

- Sweep CW signals within modulation bandwidth
- Compensates in-band variations due to analog circuit with pre-emphasis



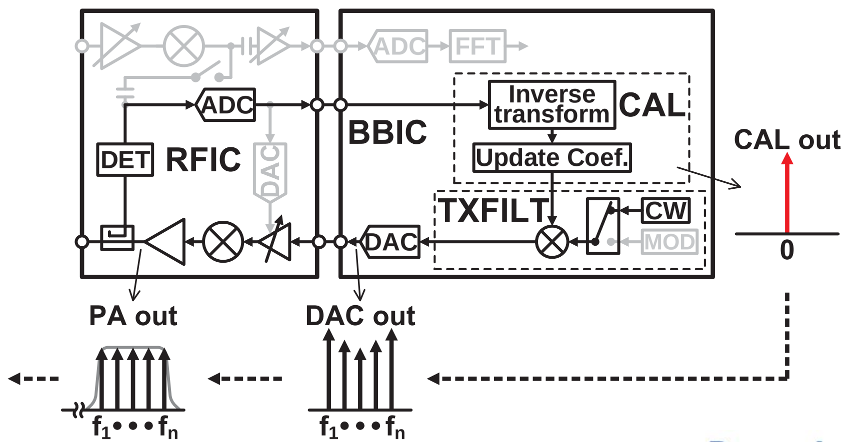
TX In-Band Cal. Procedure

- Same procedure repeats from -880MHz to +880MHz with 110MHz frequency step



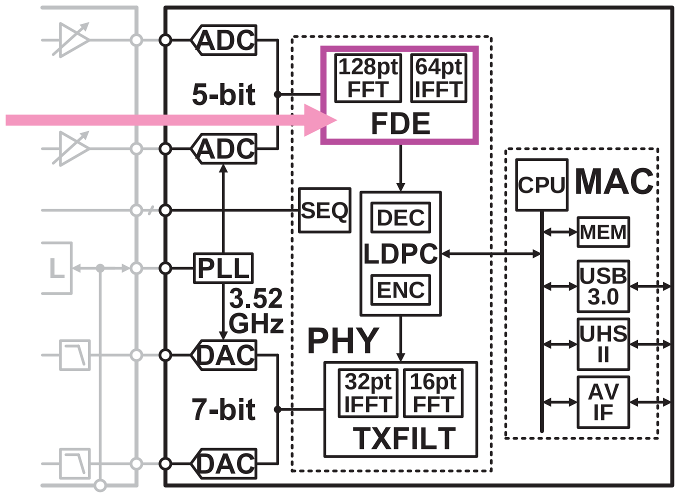
TX In-Band Cal. Procedure (Cont’)

- Flat frequency response is achieved at PA output with pre-emphasis



Frequency Domain Equalizer (FDE)

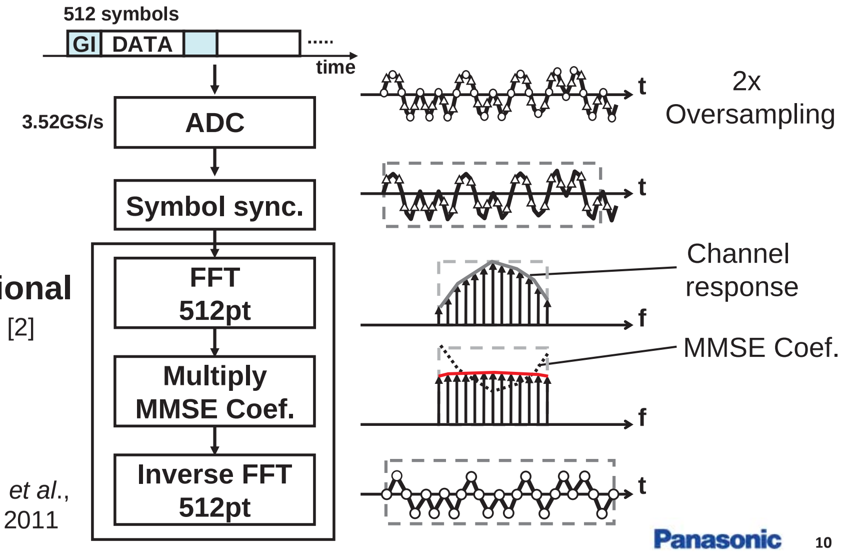
Eliminate RX signal distortion due to analog circuits as well as multipath environment



Conventional FDE

- Power hungry for symbol sync. in time domain
- Large size FFT and IFFT

Conventional FDE [2]

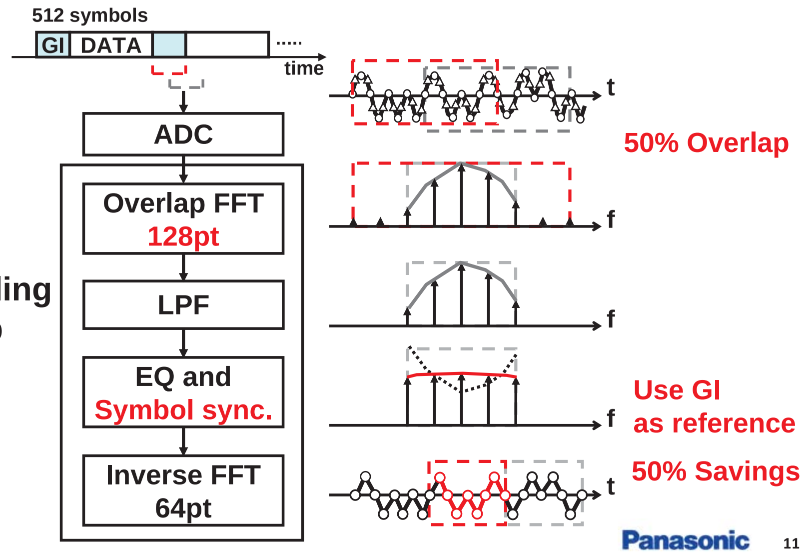


[2] F. Hsiao, *et al.*, *A-SSCC* 2011

Proposed FDE

- Small size FFT and IFFT with 50% Overlap-Save
- Symbol sync. block-by-block in frequency domain

Oversampling Overlap FDE



Comparison of FDE

	This Work	[2]	[3]
Process [nm]	40nm	65nm	65nm
Symbol rate [GS/s]	1.76	1.76	1.76
FDE input [GS/s]	3.52 (x2 O.S.)	1.76 (x1 O.S.)	1.76 (x1 O.S.)
Core clock [MHz]	220	440	330
FFT	128pt with 50% overlap	512pt	512pt
IFFT	64pt	512pt	512pt
Gate count (Data path)	284k	522k	1723k
Gate count (Channel Est.)	403k	76k	
Power (Data path) [mW]	116	208	211

[2] F. Hsiao, *et al.*, *A-SSCC* 2011
[3] F. C. Yeh, *et al.*, *VLSI-DAT* 2011

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  - Total Performance
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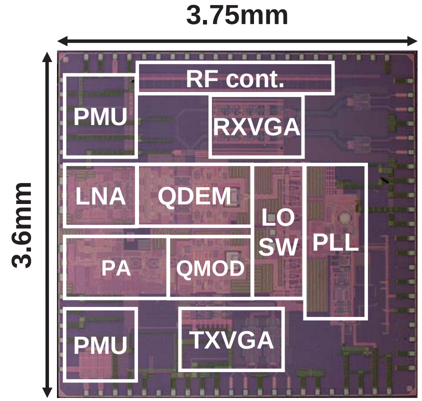
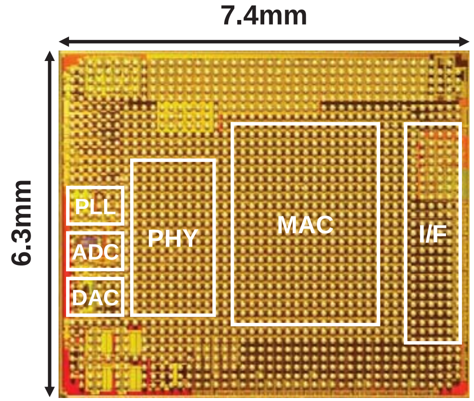
Chip Micrograph

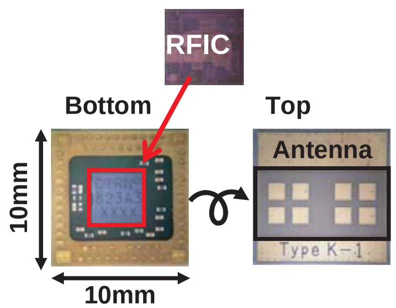
- RFIC
  - 90nm CMOS
  - 1.8V / 2.5V
- BBIC
  - 40nm CMOS
  - 1.1V / 1.8V / 3.3 V



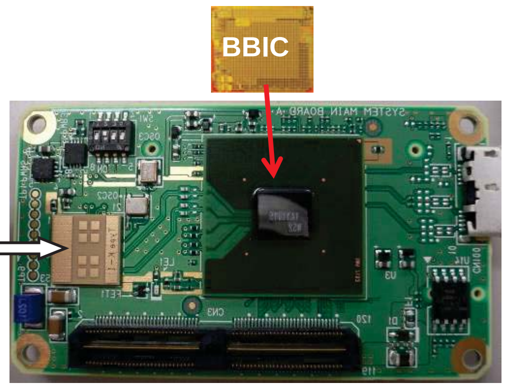


System Board of 60GHz Transceiver

- RF module with antenna
  - Antenna of 6.5dBi gain with 50 degree beam width
- System board with RF module and BBIC



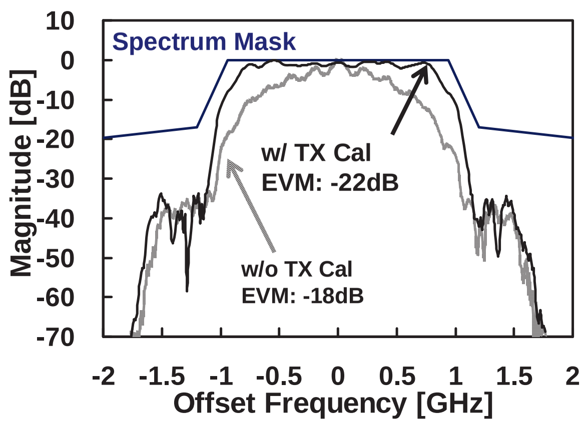
RF module with antenna

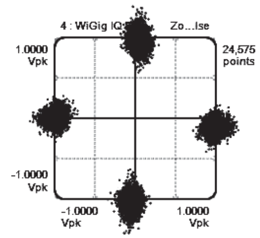


System board

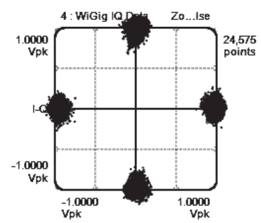
Measured TX in-band Cal. Results

- Pass-band droop improves by 11dB
- EVM improves by 4dB from -18dB to -22dB for $\pi/2$-QPSK (MCS9)





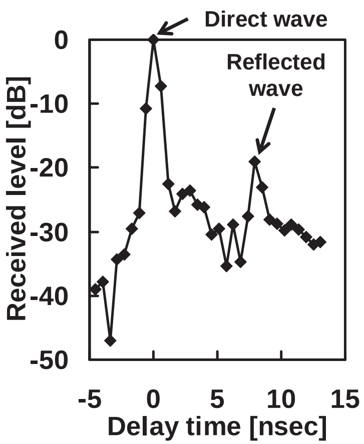
w/o TX Cal (-18dB)

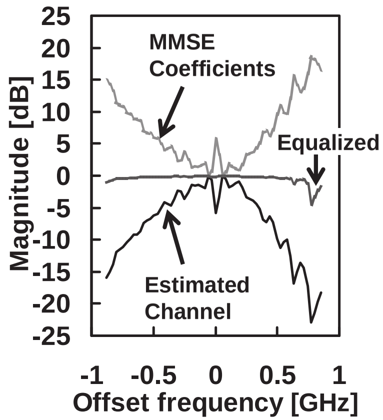


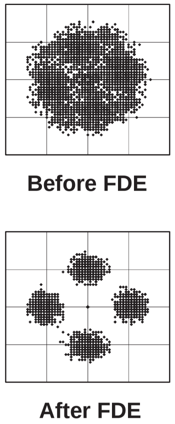
w/ TX Cal (-22dB)

Measured RX FDE Results

- Multipath results in asymmetric frequency spectrum
- FDE successfully equalizes RX signal

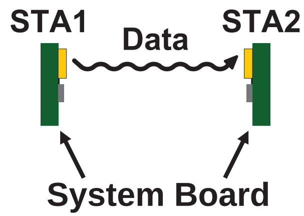


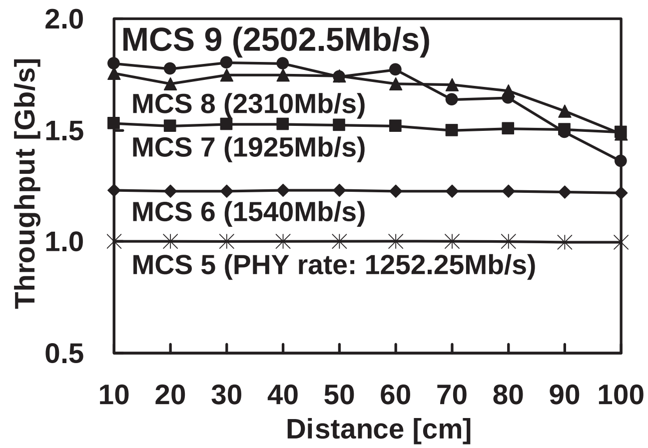




Measured MAC Throughput

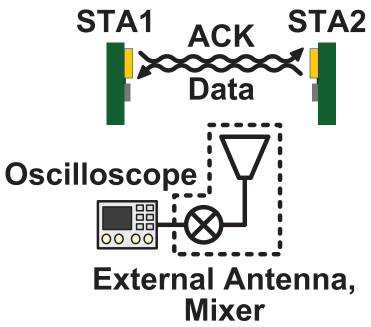
- MAC throughput over the air from STA1 to STA2
- 1.8Gb/s for up to 40cm, 1.5Gb/s for up to 1m

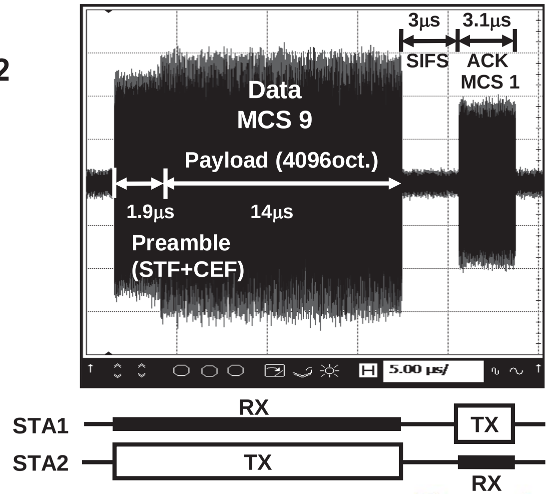




Measured Signal Waveform

- Captured over the air by external horn antenna
- Data & ACK frame exchange function with 3µs SIFS
  - Based on WiGig frame format





Performance Summary

	RFIC	BBIC
Technology	90nm CMOS	40nm CMOS
Supply voltage	1.8V / 2.5V	1.1V / 1.8V / 3.3V
Chip size	3.75mm x 3.6mm	7.4mm x 6.3mm

TX performance		
EIRP [dBm]	8.5	
EVM [dB]	-22	
Carrier / Image leakage [dBc]	-39.0 / -37.7	
Power consumption [mW]	RFIC	BBIC
	347	441*

RX performance		
Receive power range [dBm]	-78 ~ -25	
NF@maximum gain [dB]	7.1	
Power consumption [mW]	RFIC	BBIC
	274	710*

* excluding interface

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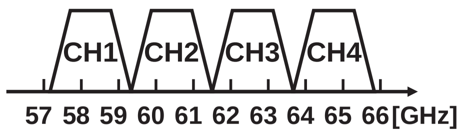
Pros and Cons of Millimeter Wave

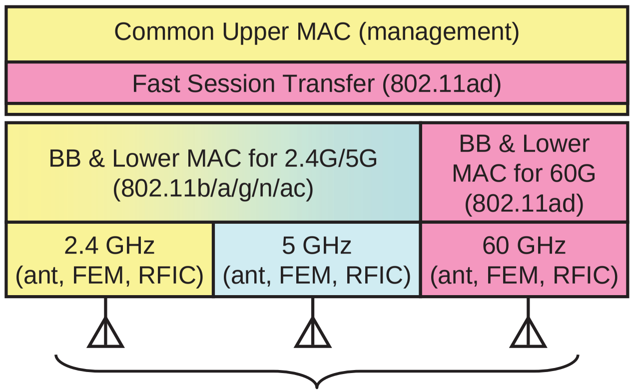


Limited to these use cases?

- ☺ **Wider bandwidth**
  - **2.16GHz/CH, 9GHz/4CH at millimeter wave vs. up to a few hundreds MHz at Microwave freq.**
- ☹ **Limited number of channels**
- ☹ **Large path loss and severe shadowing effects, resulting in limited communication distance**

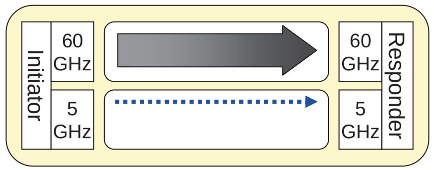
Fast Session Transfer (FST)

- **Enables seamless integration of 60GHz with 2.4G/5GHz**
- **Allows transition from any band/channel to any other band/channel**
- **Supports both simultaneous and non-simultaneous operation**

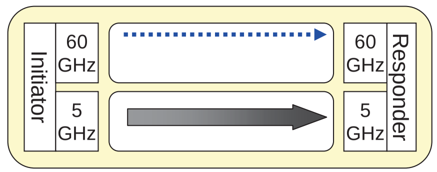


Proposed FST

Case1: 60GHz is used for data



Case2: 5GHz is used for data



Data
Throughput Measurement to minimize FST switching time

Assumption: FST occurs every 5 sec. It takes 500ms for conventional and 20ms for proposed.

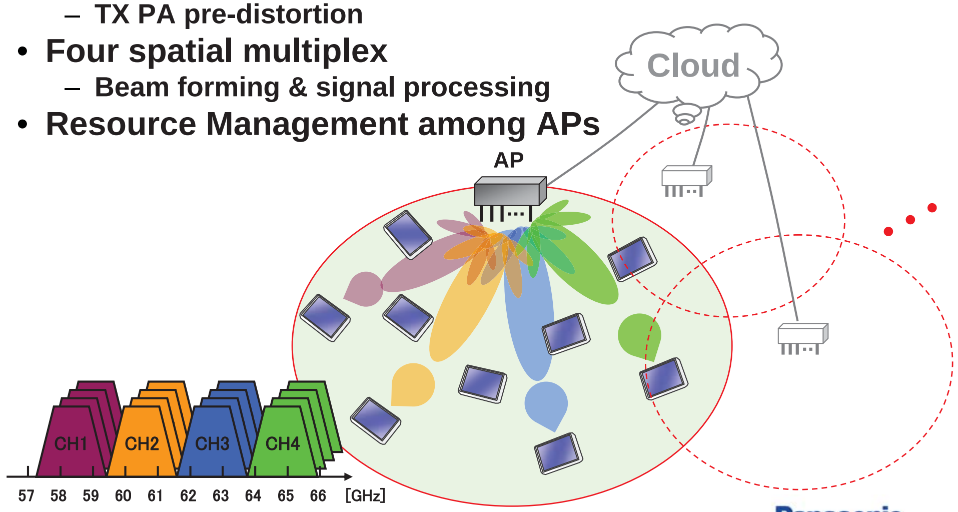
Data size (GB)	5GHz Only	60GHz Only	Conventional	Proposed
20	1638.4	176	166.34	151.94
50	4096	440	418.72	382. 24
100	8192	880	837.45	764.49

[Sec]

10% reduction of data transfer time

What is Next?

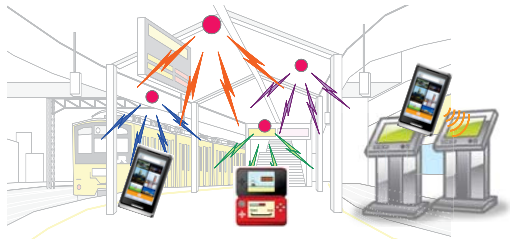
- Co-existence of adjacent channels
  - Interference avoidance MAC
  - RX interference canceller
  - TX PA pre-distortion
- Four spatial multiplex
  - Beam forming & signal processing
- Resource Management among APs



Future Millimeter Wave Systems


Office, Shop & Store


Airplane or Train


Public area

Target use-case of "The research and development project for expansion of radio spectrum resources" of The Ministry of Internal Affairs and Communications, Japan.

Conclusion

- Panasonic has developed a prototype chipset, targeting mobile usage
  - 1.8Gb/s for up to 40cm and 1.5Gb/s for up to 1m in MAC throughput with lower than 1W
  - Ultra-fast file transfer and low latency HD streaming
- On-going research will make 60GHz wireless more robust and ease of use in various applications

Panasonic

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