東南大學 SOUTHEAST UNIVERSITY

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A Perfect Solution for Indoor High Throughput Short-Range Wireless Access: mmWave WLAN + FTTR

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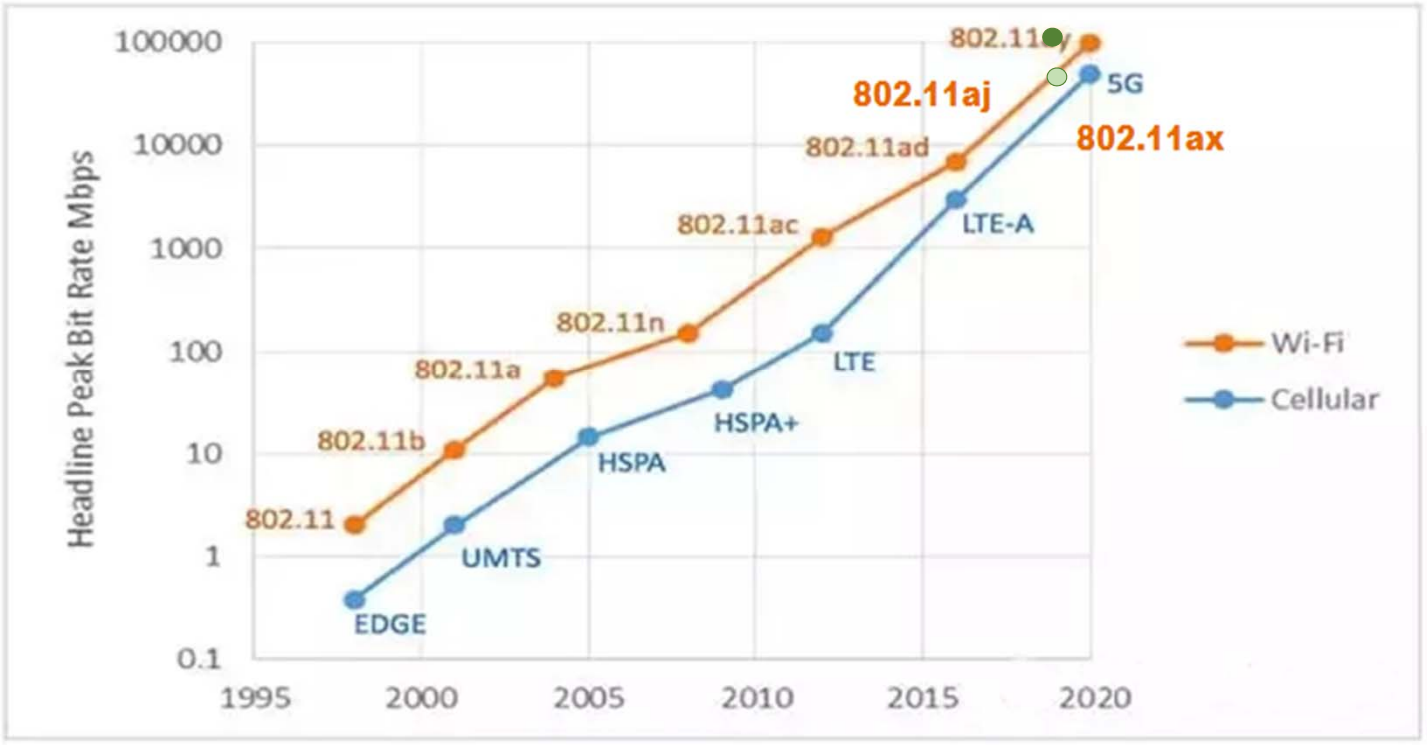
Content

- Background
- IEEE 802.11aj(45GHz) and Spectrum Allocation
- System Verification and mmWave Chip Design
- FTTR + mmWave WiFi
- Conclusion

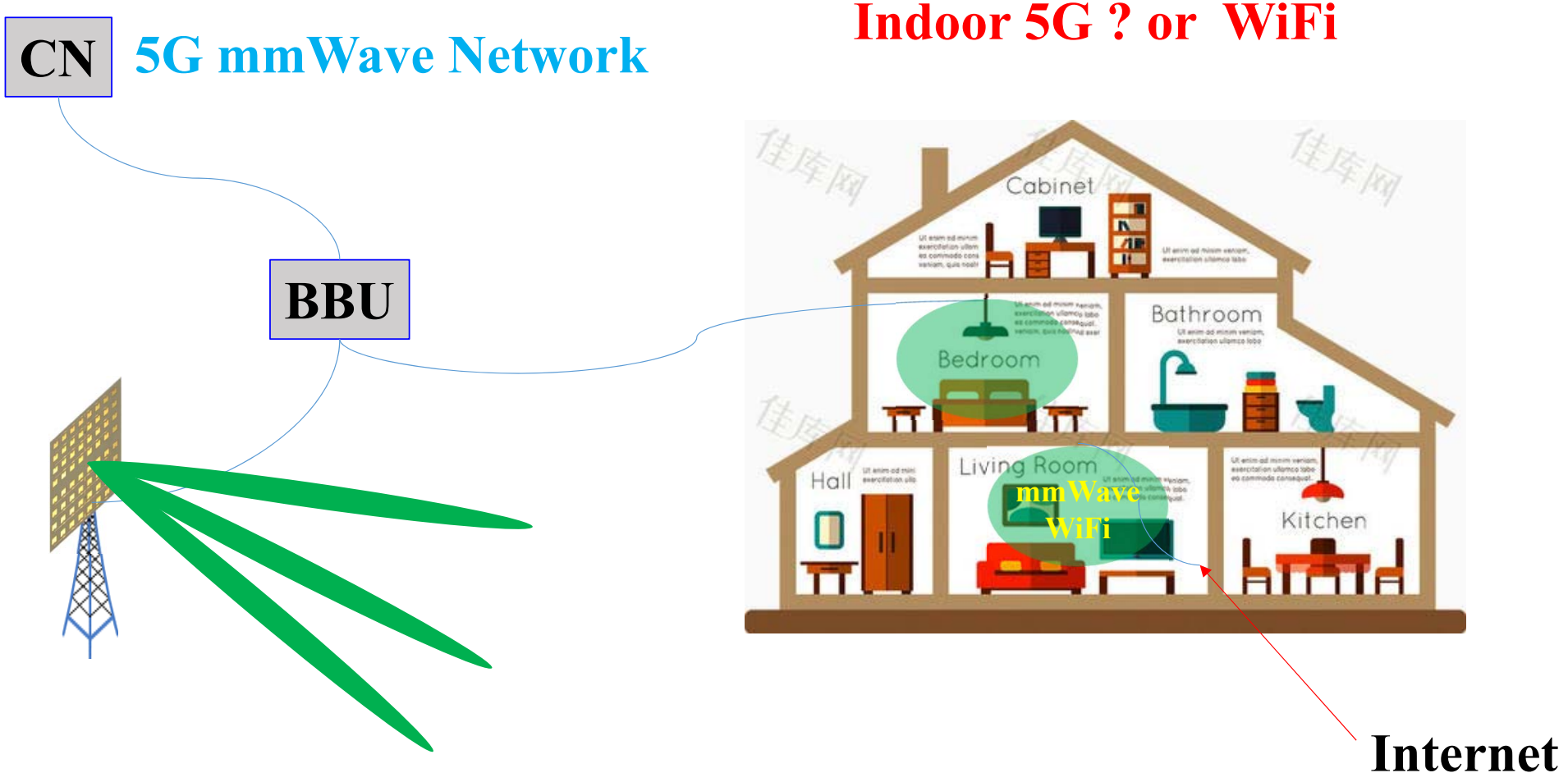
Background

More than 70% of mobile terminal data transmission is completed through WiFi: 1) Trends in last two decades: WLAN Speed is ~x10 higher than cellular network, 2) Convenience and cost advantage.



Source: according to public reports

Background


CN
5G mmWave Network
BBU
Indoor 5G ? or WiFi
Cabinet
Bedroom
Bathroom
Hall
Living Room
mmWave
WiFi
Kitchen
Internet

Background

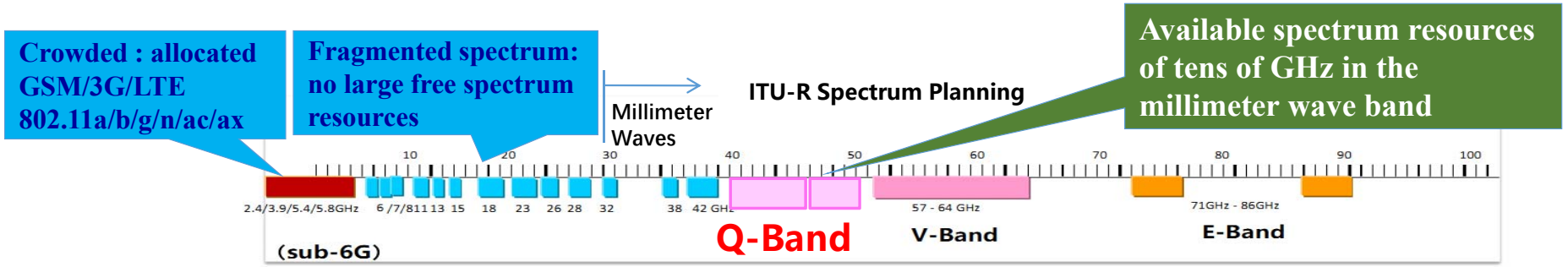
The low frequency band of wireless communication (sub-6GHz) is basically exhausted. The development of millimeter wave band has become a hot topic.

The demand for wireless data throughput is growing from ~100 Mbps to ~1000 Mbps

The spectrum in low frequency band is basically exhausted. The interference in unauthorized 2.4/5.8 GHz bands is serious.

Millimeter wave (MMW) spectrum resources are abundant.

MMW Technology is rapidly developed, ready for large scale applications.



Background

- In 2010, Prof. Wei Hong and his team from the State Key Laboratory of Millimeter Waves, Southeast University, proposed a new millimeter wave short and long distance communication standard to CWPAN, named Q-LINKPAN (40.5-50.2GHz: Q-Band: Link +PAN).
- In 2012, a new standard IEEE 802.11aj TG was founded.
- In 2013, MIIT issued 9.5GHz spectrum to develop Q-LINKPAN .
- In 2014, 45GHz Q-LINKPAN listed in MOST “863” 5G major program.
- In 2015, 45GHz band is supported by 5G Key Project.
- IEEE802.11aj has been passed the final voting in Sept., 2017, and released in May, 2018.

45GHz
Ultra-high Speed Millimeter Wave Short and Long Distance Communication Standard of China

- Supporting 10Gbps communication
- IEEE 802.11aj , the first international standard leading established by China in the 802.11 family.

Background

China millimeter wave short distance communication standard （2018）


GB

中华人民共和国国家标准

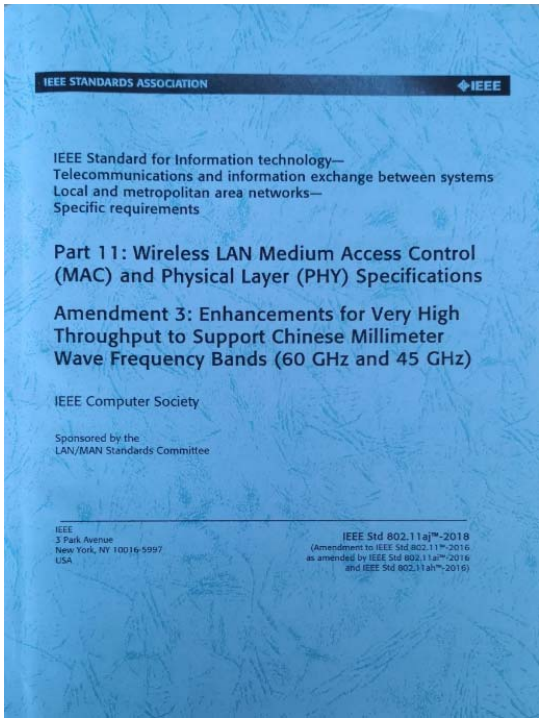
信息技术　系统间远程通信和信息交换
局域网和城域网　特定要求　Q波段
超高速无线局域网媒体访问控制和
物理层规范


工业和信息化部文件

工信部无〔2013〕502号

工业和信息化部关于发布
40—50吉赫兹(GHz)频段移动业务中
宽带无线接入系统频率使用事宜的通知

IEEE802.11aj (2018)


IEEE STANDARDS ASSOCIATION　IEEE

IEEE Standard for Information technology—
Telecommunications and information exchange between systems
Local and metropolitan area networks—
Specific requirements

Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

Amendment 3: Enhancements for Very High Throughput to Support Chinese Millimeter Wave Frequency Bands (60 GHz and 45 GHz)

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 802.11aj™-2018
(Amendment to IEEE Std 802.11™-2016
as amended by IEEE Std 802.11ae™-2016
and IEEE Std 802.11ah™-2016)

IEEE Standard Association Outstanding Contribution Award


Certificate of Appreciation

The IEEE Standards Association acknowledges with appreciation

Wei Hong

for outstanding contributions to the development of
IEEE Standard 802.11aj™-2018

IEEE

CWPAN Excellent Team Leader Award by NISSTC


NITS

兹授予：东南大学洪伟

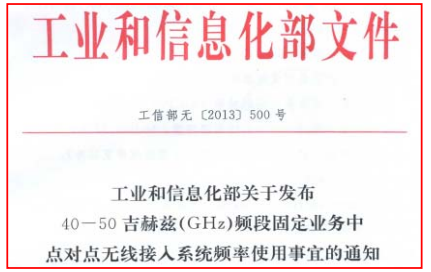
2012年度无线个域网标准工作组

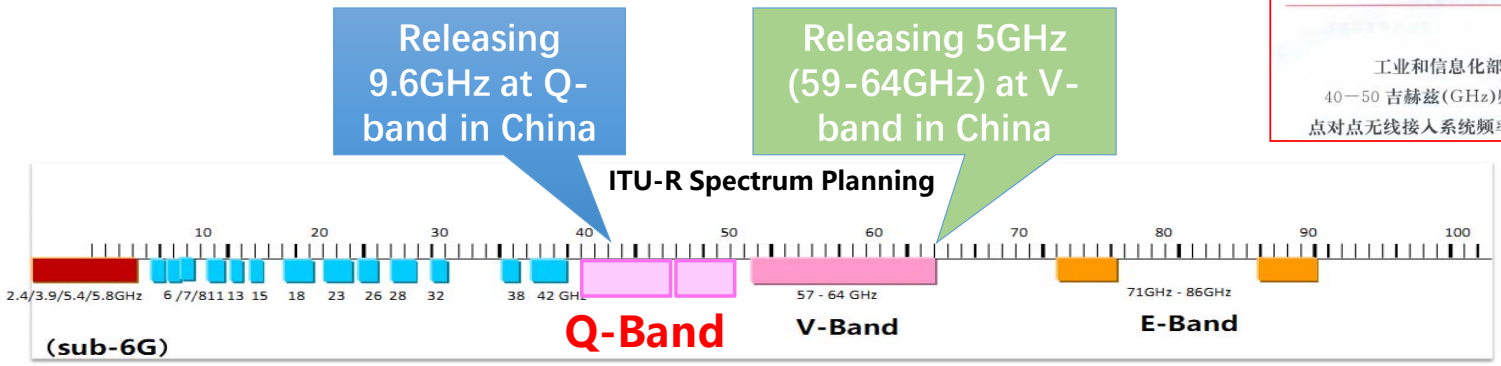
优秀组长奖

IEEE 802.11aj(45GHz) and Spectrum Allocation

Current situation for Millimeter wave spectrum allocation in China: Q-band spectrum has been released for indoor and outdoor high-speed applications.

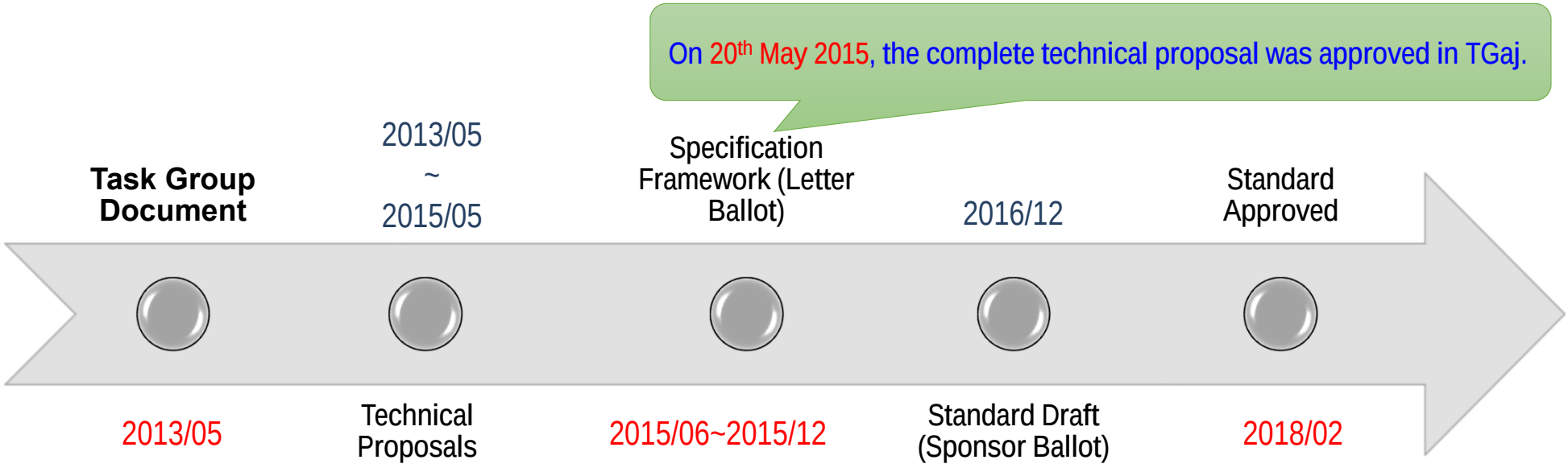
- The Ministry of industry and information technology officially issued the 45GHz spectrum proposal in Dec, 2013.
  1) Mobile（TDD）：42.3GHz~47GHz、47.2GHz~48.4GHz;
     （MIIT [2013] No. 502 document）-- un-lincensing
  2) Fixed（FDD）：40.5GHz~42.3GHz/48.4GHz~50.2GHz。
     （MIIT [2013] No. 500 document）





IEEE 802.11aj(45GHz) and Spectrum Allocation

IEEE 802.11aj Development Time Line



- On 20th January 2016, IEEE 802.11aj D1.0 was approved by the IEEE 802.11 WG.

TG/WG	BallotID	OpeningDate	Dur (d)	Ballot Close Date	Title	BallotType	Pool	Approve	Disapprove	Invalid	Abstain	Return	%Return	%Abstain	%Approve	comments
TGaj	217	2015-12-21	30	2016-01-20	IEEE 802.11aj Draft 1.0 Technical	Technical	378	221	30	13	31	295	78.04	10.51	88.05	174

IEEE 802.11aj(45GHz) and Spectrum Allocation

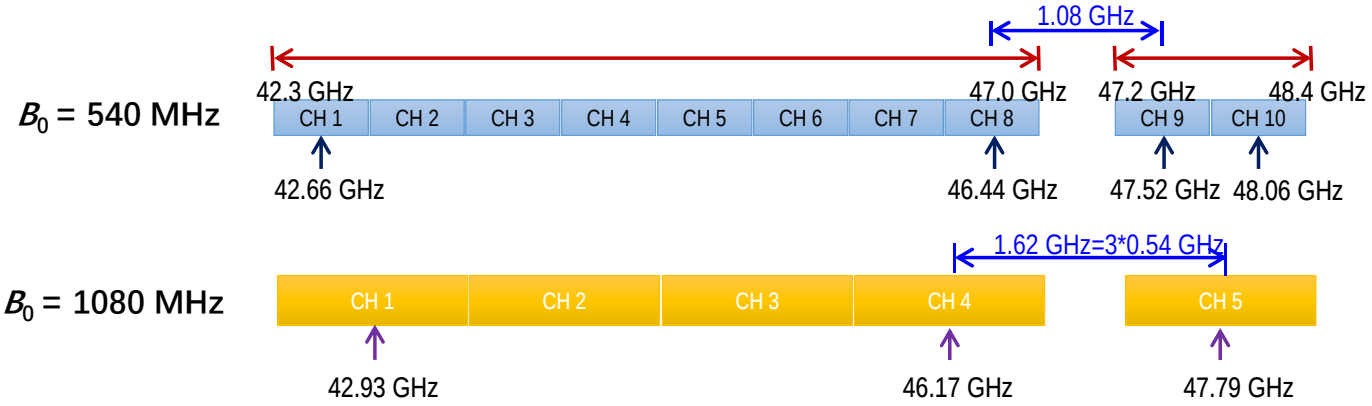
11aj (45GHz) Channelization: Supporting 10 / 5 networks simultaneously working without mutual interference

B_0 = 540 MHz:

$$f(n)\,[\mathrm{GHz}] = \begin{cases} 42.66 + 0.54(n-1) & 1 \le n \le 8 \\ 47.52 + 0.54(n-9) & n = 9,10 \end{cases}$$

B_0 = 1080 MHz:

$$f(n)\,[\mathrm{GHz}] = \begin{cases} 42.93 + 1.08(n-1) & 1 \le n \le 4 \\ 47.79 & n = 5 \end{cases}$$

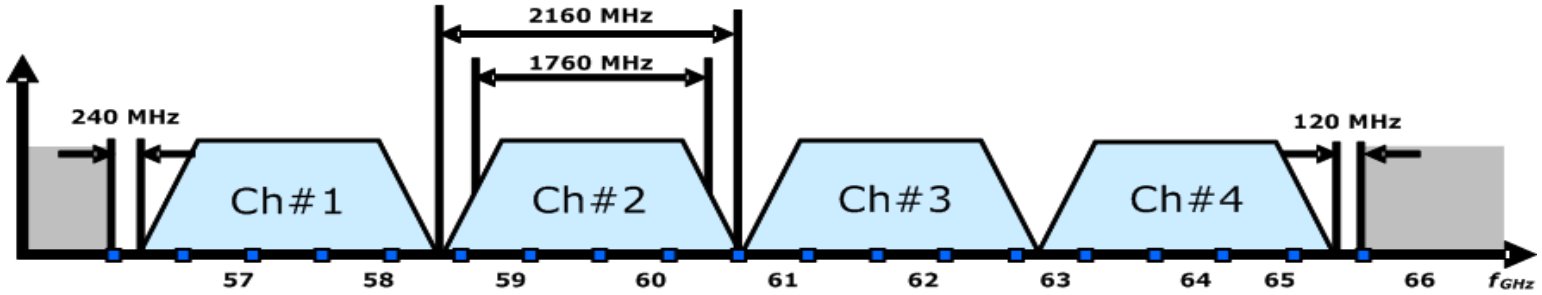


IEEE802.11aj(45GHz) standard includes 10 channels with a bandwidth of 540 MHz or 5 channels with a bandwidth of 1080 MHz

IEEE 802.11aj(45GHz) and Spectrum Allocation

IEEE802.11ad channel in the world：there are only 3 channels in most countries, at most 4 channels in some countries.

The IEEE802.11ad standard protocol includes four channels with a bandwidth of 2160MHz。

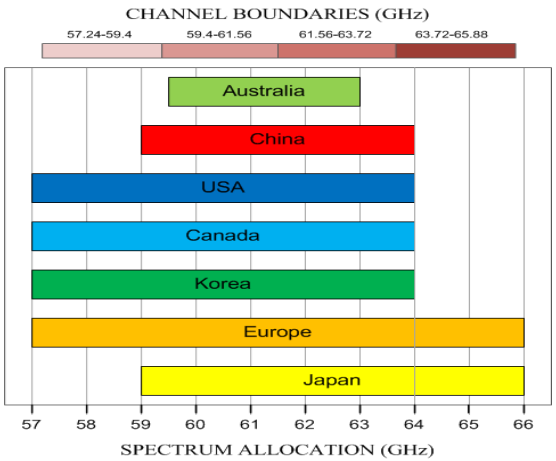


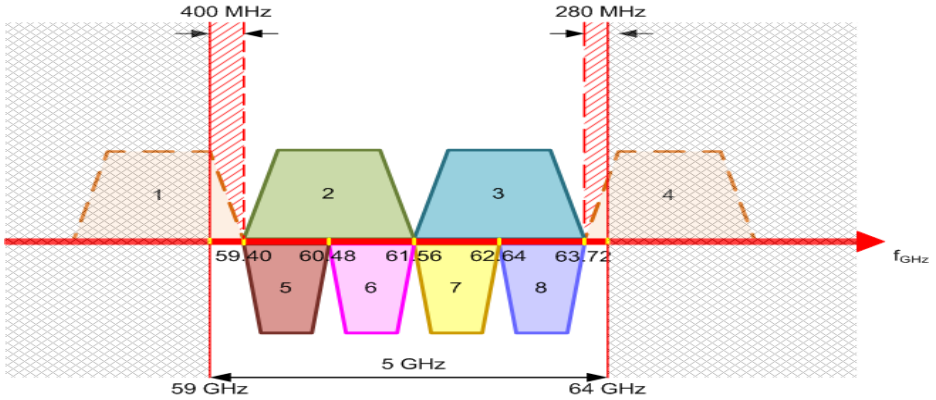
Channel Number	Lower Freq. (GHz)	Center Freq. (GHz)	Upper Freq. (GHz)	Nyquist BW (MHz)	Channel Spacing (MHz)
1	57.240	58.320	59.400	1760	2160
2	59.400	60.480	61.560	1760	2160
3	61.560	62.640	63.720	1760	2160
4	63.720	64.800	65.880	1760	2160

IEEE 802.11aj(45GHz) and Spectrum Allocation

IEEE802.11ad channel in China：There are only 2 channels (to be recovered recently)

The IEEE802.11ad standard protocol in China includes only two channels with a bandwidth of 2160MHz





Channelization for 60GHz bands in China

Limited by the number of available channels, IEEE802.11ad cannot independently support more than three non-interference 2.16GHz networks in China.

IEEE 802.11aj(45GHz) and Spectrum Allocation

802.11ax Channel：there is only 160 MHz channel in China

The channel bandwidth of IEEE802.11ax standard protocol is divided into 20, 40, 80, 160 and 80 + 80MHz channels. The peak rate is 10Gbps, supporting 8 streams

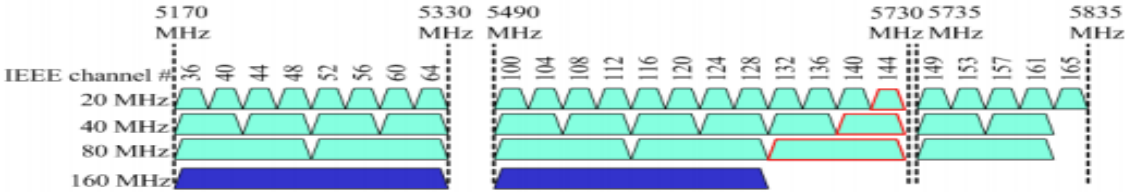


Figure 1: US and Global Operating Class Channel Allocation

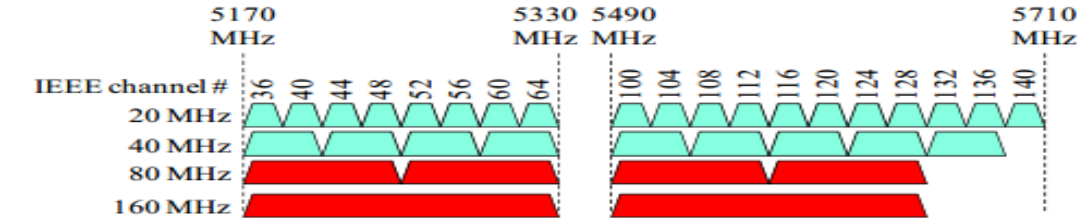


Figure 2: Europe and Japan Class Channel Allocation

Limited by the number of available channels, IEEE 802.11ax cannot independently support more than three 160MHz networks.

IEEE 802.11aj(45GHz) and Spectrum Allocation

IEEE802.11 comparison（aj : ad）— Spectrum utilization（4:1）Distance（2:1）

key technology		IEEE802.11aj(45G)	IEEE802.11ad（60GHz）	IEEE802.11aj（60GHz）
Bandwidth		45GHz（band in China）	60GHz（band in China）	60GHz（band in China）
Channel bandwidth	⚠	540/1080MHz	2160MHz	2160MHz/1080MHz
Channel number	✔	10*540/5*1080MHz	2*2160MHz	2*2160/4*1080MHz
Peak rate	✔	**15Gpbs**	**6.76Gpbs**	**3.8Gbps**
Spectral efficiency	✔	13.9bit/Hz/s	3.13bit/Hz/s	3.13bit/Hz/s
Antenna Tech	✔	MIMO Antenna	Antenna Array	Antenna Array
Streams	✔	4 streams	1 stream	1 stream
Transmission loss（LOS）	✔	The path loss of 45GHz is smaller than that of 60GHz by **2.5dB.**		
Performance difference of millimeter wave front end	✔	Under the same Silicon-based process, the transmission power for 45GHz is **2dB** higher than 60GHz and the noise figure is **0.5dB** lower.		
Block Reception for Signals	✔	better	weak	weak

- **Peak spectrum utilization：** IEEE802.11aj(45G) is about **4 times higher** than IEEE802.11ad**.**
- **Environmental adaptability:** IEEE802.11aj (45g) is **more suitable** for indoor complex environment communication**.**
- **Compatibility:** IEEE802.11aj (45g) does not need to be **compatible** with other protocols; IEEE802.11aj (60g) need to be **compatible** with ieee802.11ad**.**
- **TR distance**: IEEE802.11aj (45ghz) is **twice** as long as IEEE802.11ad**.**

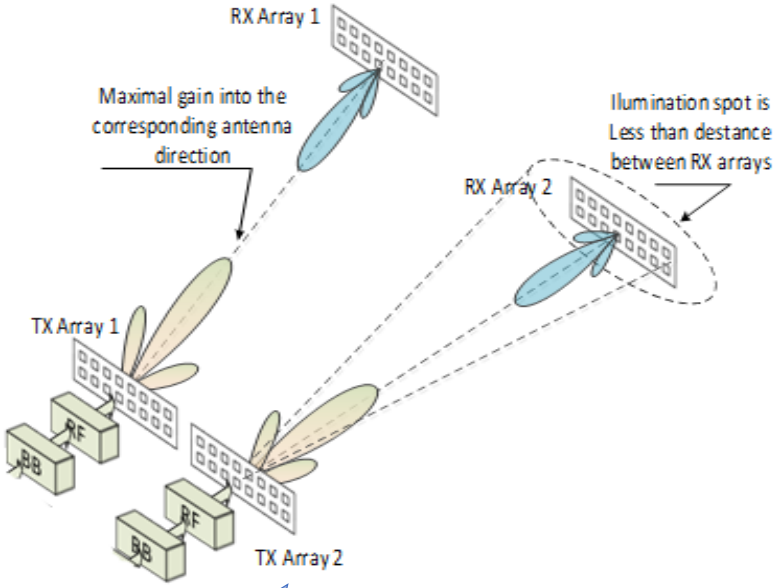
IEEE 802.11aj(45GHz) and Spectrum Allocation

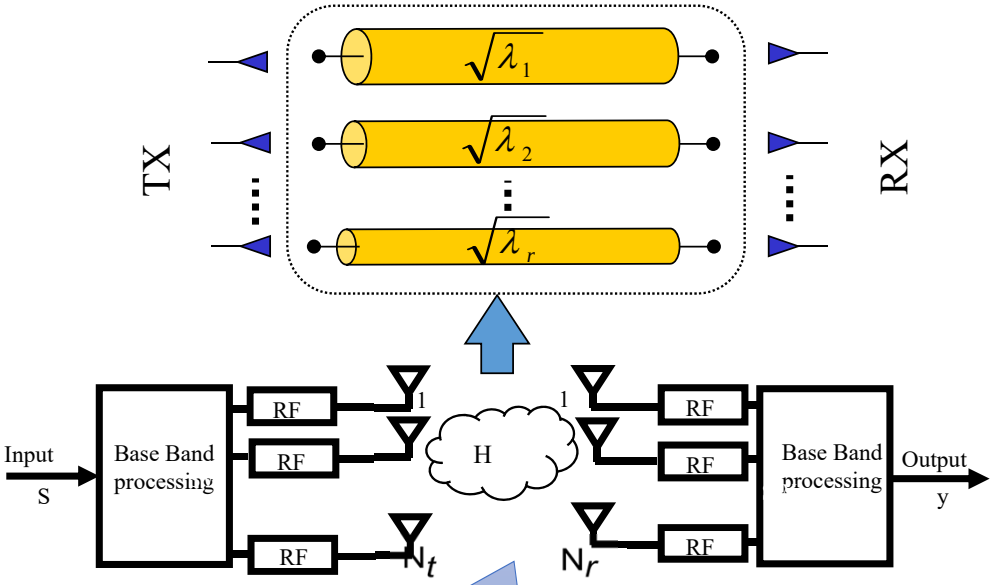
IEEE802.11 comparison (aj : ax) — large free spectrum resources, less interference and small device size for 11aj

key technology		IEEE802.11aj(45G)	IEEE802.11ax
Bandwidth	⚠	45GHz（band in China)	Sub-6GHz（band in China)
Channel bandwidth	✔	540/1080MHz	160MHz
Channel number	✔	**10/5**	**2**
Peak rate	✔	**15Gpbs**	**10Gpbs**
Spectral efficiency	⚠	13.9bit/Hz/s	62.5bit/Hz/s
Antenna Tech	⚠	MIMO Antenna	MIMO Antenna
Streams	⚠	4 streams	8 streams
Transmission loss（LOS)	⚠	The path loss of 45GHz is larger than that of sub-6GHz by **17.8dB.**	
Performance difference of millimeter wave front end	⚠	Under the same Silicon-based process, 11ax has obvious advantages than 11aj. But the size of 45ghz antenna is small (1 / 7.75)	
Block Reception for Signals	⚠	weak	strong
Bandwidth	✔	large	small

- **Spectrum resources:** there is **more available spectrum resources** for IEEE802.11aj(45G) than IEEE802.11ax**.**
- **Interference issue:** IEEE802.11aj (45G) has **less interference between networks and better confidentiality**
- **Compatibility**: IEEE802.11ax needs to be **compatible** with IEEE802.11a/b/g/n/ac**.**
- **Complexity**: 11ax needs to support 256QAM and 8 spatial streams, with **very high technical complexity.**

Comparison of IEEE802.11 system architecture: MIMO antenna and antenna array

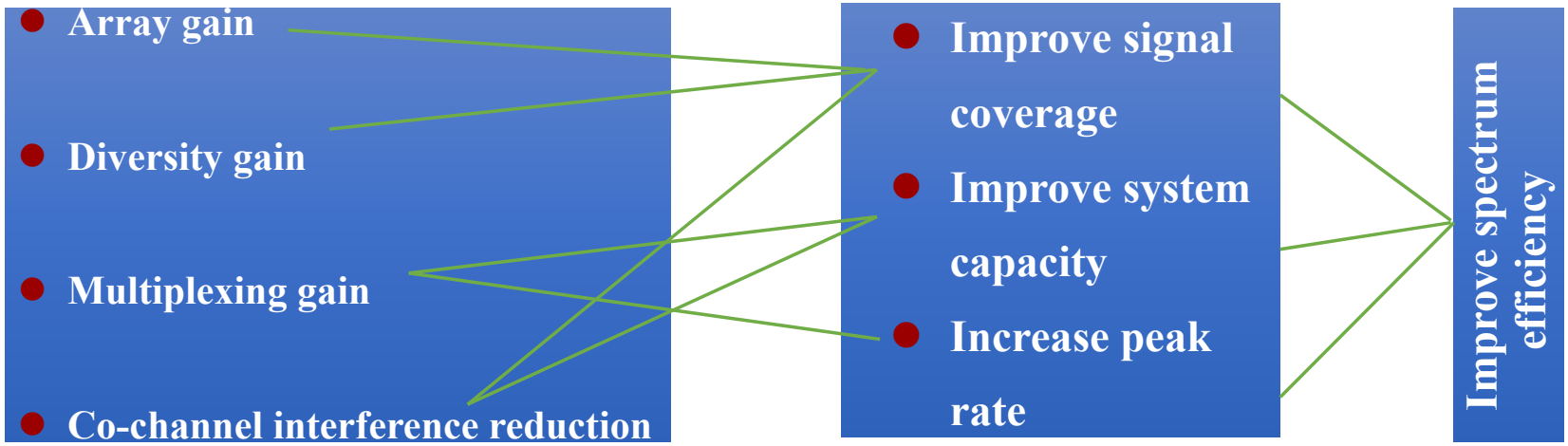




IEEE802.11ad: antenna array is used to overcome the transmission fading characteristics in 60GHz band.

IEEE802.11aj(45GHz), ax: MIMO technology is used to obtain diversity and multiplexing gain, with high-frequency spectral efficiency and high reliability, realizing high-speed transmission.

IEEE802.11 technical features: there are differences in spectrum utilization, and 11aj / ax has advantages.



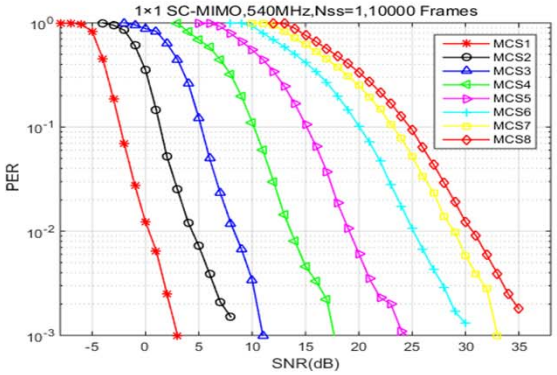
	Array Gain	Diversity gain	Multiplexing gain	Interference reduction gain
IEEE802.11ad	√	×	×	√
IEEE802.11aj(45GHz)	√	√	√	√
IEEE802.11ax	√	√	√	√

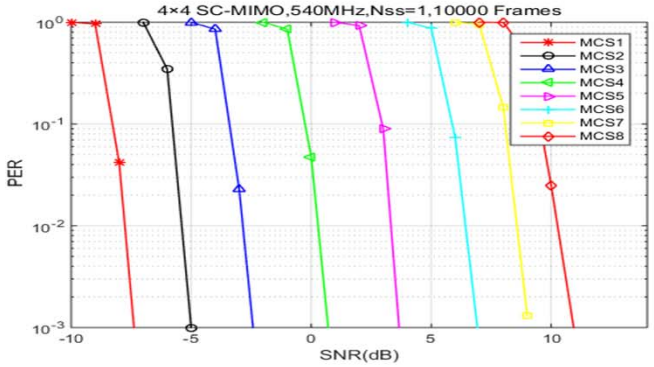
With 4 antennas, the diversity gain is about 2dB-4dB.

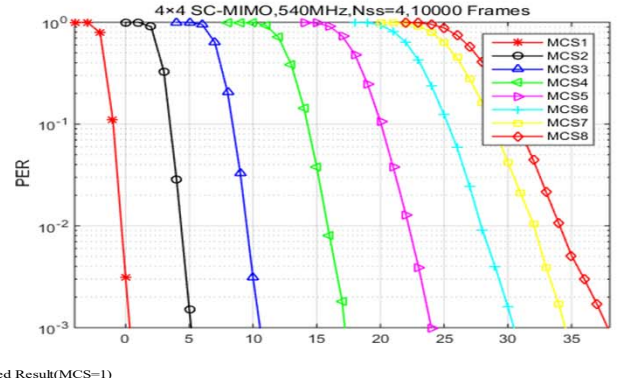
System Verification and mmWave Chip Design

Performance of 802.11aj

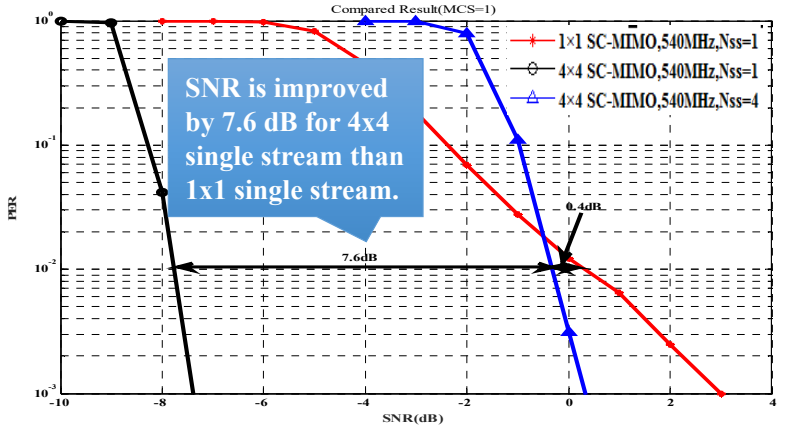
——The SNR of MIMO 4 antenna (single stream) is 7.6 dB higher than that of single antenna (single stream)





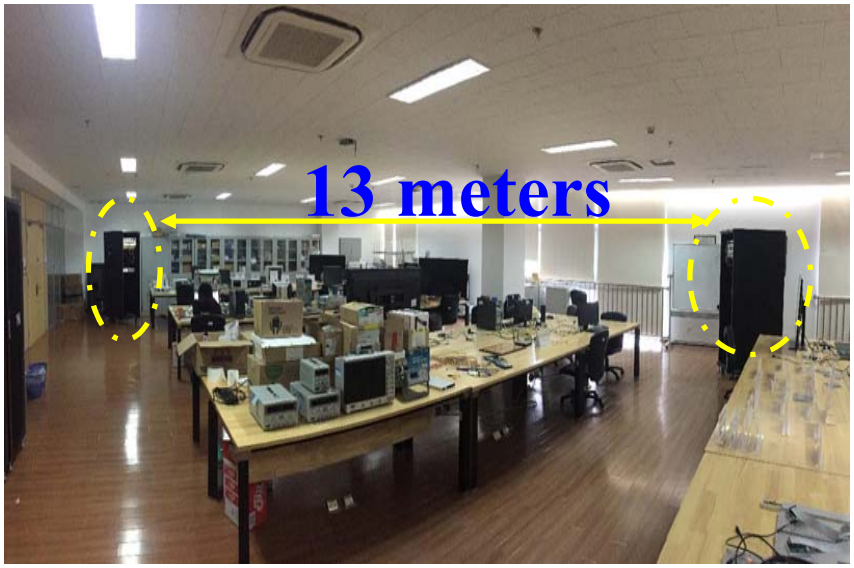


MIMO provides diversity gain (curve slope), array gain, multiplexing gain and interference suppression gain



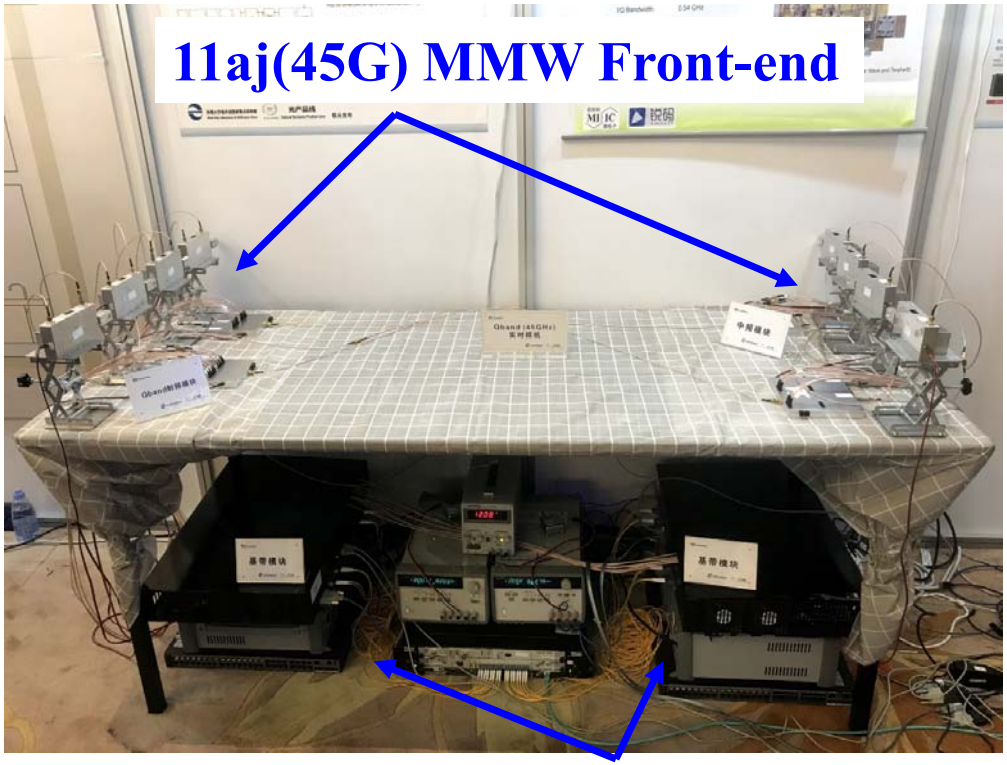
System Verification and mmWave Chip Design

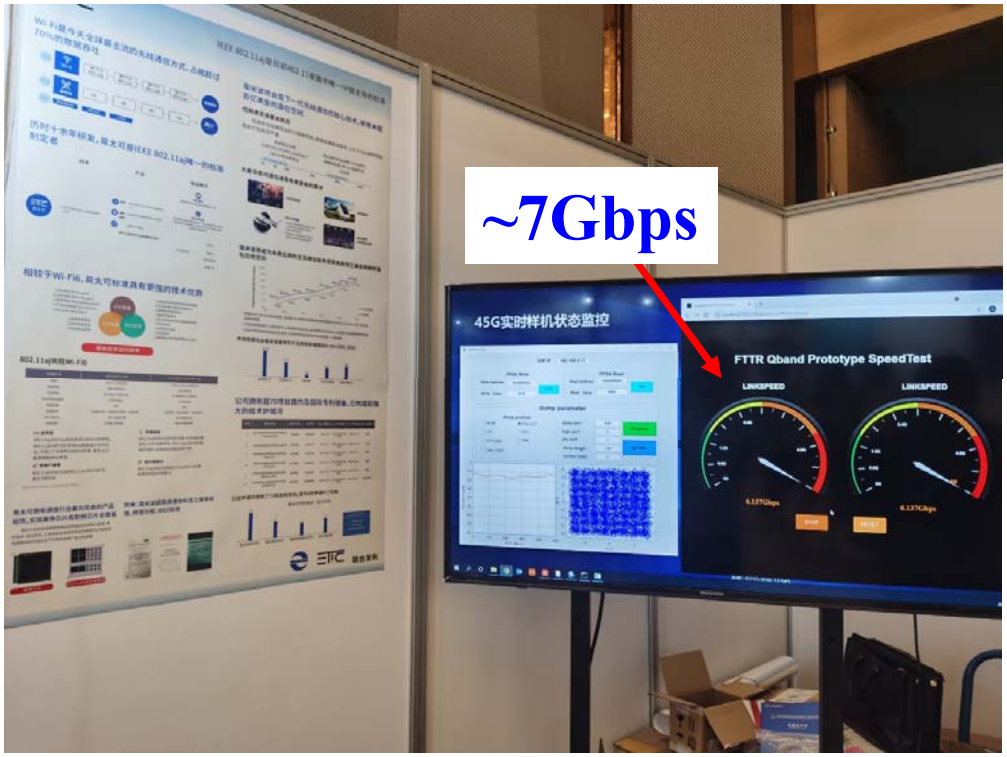
802.11aj Prototype I —— TR distance over 13 meters, speed 2Gbps (2016) -> 10Gbps (2019)



System Verification and mmWave Chip Design

802.11aj Prototype II ——TR Distance of 3M, wireless service rate ~ 7Gbps (jointly developed with H company)





Possible Applications

Data rate > 10Gbps, Transmission range >10m

User senarios of Q-LINKPAN-S/IEEE802.11aj(45GHz)






System Verification and mmWave Chip Design

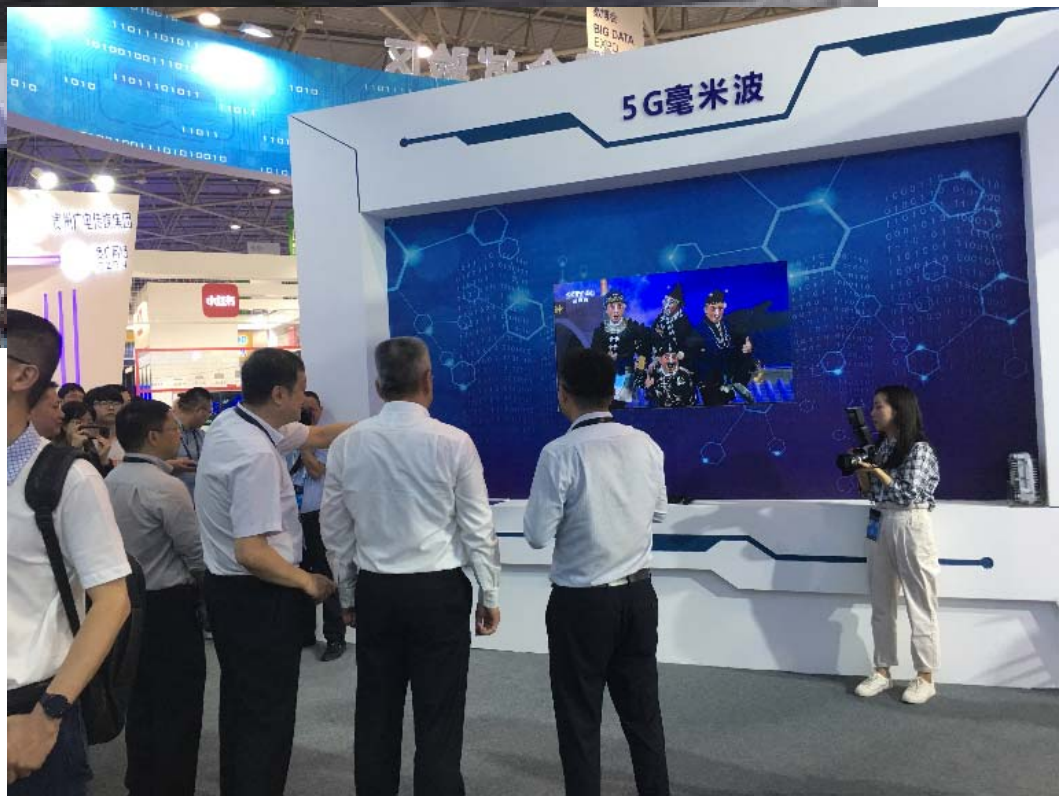
Q-band outdoor long-distance communication products have been commercially tested.

Commercial products:
Antenna gain: 36 / 41dBi
Peak rate: 1.7gbps

Shanghai Oriental pearl TV Tower

King Tower

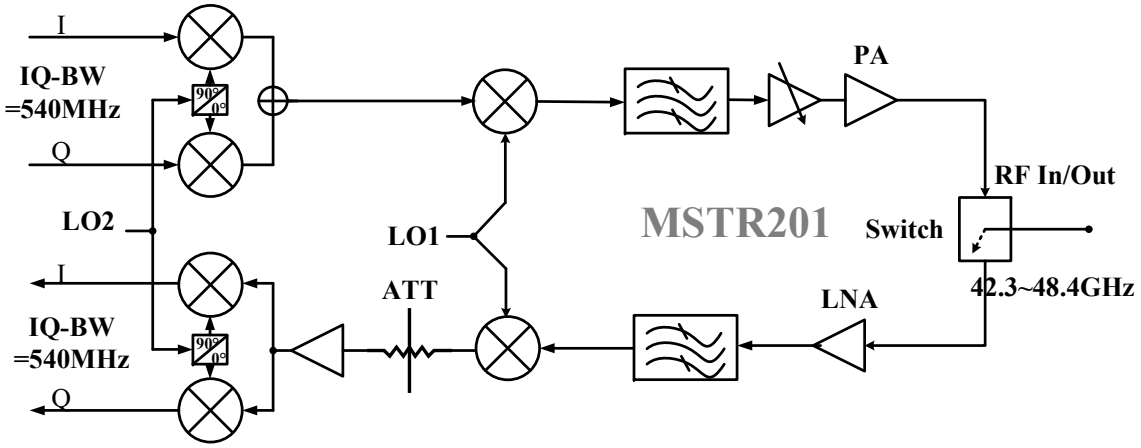
System Experimental Verification

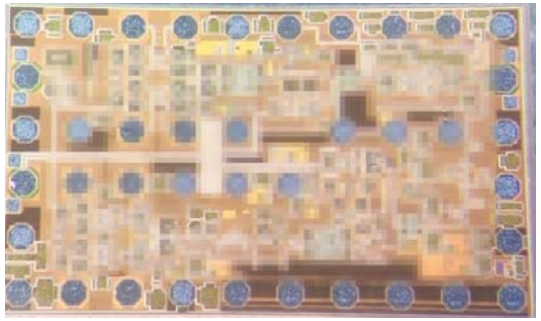


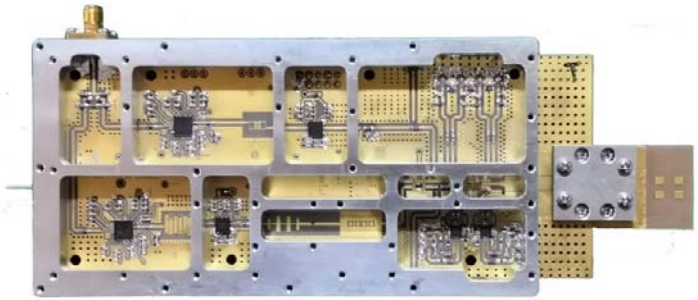
45GHz band millimeter wave demonstration system for home environment:
Antenna: open waveguide
Antenna gain: ~ 6dBi
Coverage: > 10m

System Verification and mmWave Chip Design

45GHz RF front-end transceiver MSTR201







		MSTR201
	Frequency	42.3~48.4GHz
TX	Output P1dB	14 dBm
	TX Conv. Gain	35 dB
	Gain Flatness	±1dB
RX	NF	7.5 dB
	RX Conv. Gain	30~65 dB
	Gain Flatness	±1dB
Common	DC Power	0.4W
	I/Q BB bandwidth	0.54 GHz
	IMRR	25 dBc
	Working Temp	-40~105 °C
	Size	4 mm X 2.3 mm
	Package	WLCSP

45/60GHz Silicon-based RFIC Spec Comparison

	Spec	Commercial Chip A	Commercial Chip B	Commercial Chip C	MSTR201
	Channel Number	1	1	16	1
	Integration Level	Separated T/R	Separated T/R	Integrated T&R	Integrated T&R wi. Switch
	Topology	Superheterodyne	Superheterodyne	Superheterodyne	Superheterodyne
	Process	SiGe	SiGe	SiGe	SiGe
	Frequency (GHz)	57~64	57~64	57~71	42.3~48.4
Tx	max Gain(dB)	38	35	-	36
	P1dB(dBm)	11	15	10 (single-ch)	13.5
	Image rejection(dB)	34	40	30	25
	sideband suppression(dBc)	20	30	-	30
	Carrier suppression(dB)	20	30	-	30
	Power Dissipation(W)	0.8	1	5.9	0.66(Tx)+0.7(PLL)
Rx	max Gain(dB)	67	69	65	65
	Noise Figure(dB)	7	8	7	6.5
	input IP3(dBm)	-27	-9	-	-20
	Input P1dB(dBm)	-36	-19	-18	-30
	Image rejection(dB)	35	35	35	25
	sideband suppression(dBc)	27	23	-	30
	Power Dissipation(W)	0.61	0.82	4.3	0.35(Rx)+0.7(PLL)
PLL	Phase noise @ 100 kHz(dBc/Hz)	-72	-75	-	-80
	Phase noise @ 1 MHz(dBc/Hz)	-86	-93	-96	-93
	Phase noise @ 10 MHz(dBc/Hz)	-111	-114	-117	-115

FTTR + mmWave WiFi (Perfect Match)

China has accelerated the construction of 5G and gigabit optical networks, and the "double Gigabit" has entered in a three-year critical development period.

◆ **Government work report in 2021**
(Mar. 9, 2021)

中华人民共和国工业和信息化部
Ministry of Industry and Information Technology of the People's Republic of China

Action plan for coordinated development of "dual Gigabit" networks (2021-2023)

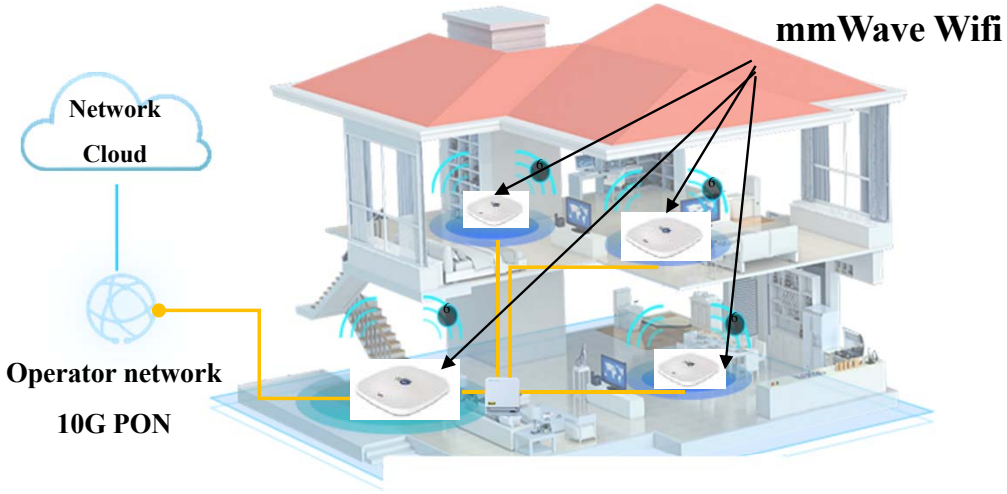
2021: **20** Gigabit Cities

2023: **100** Gigabit Cities

In three years, a "double Gigabit" network infrastructure covering urban areas and conditional townships will be built, realizing that fixed and mobile networks generally have "Gigabit to home" capacity, and accelerate the development of Gigabit optical networks and 5G users.

FTTR + mmWave WiFi (Perfect Match)

Fiber-To-The-Room(FTTR) helps to realize the whole house Gigabit coverage of WLAN.



FTTR

In 2021， More than 30 provincial companies in China have released FTTR service packages.

100%
Easy to Deploy

Threading robot
Invisible optical cable

100X
Increasing Data Rate

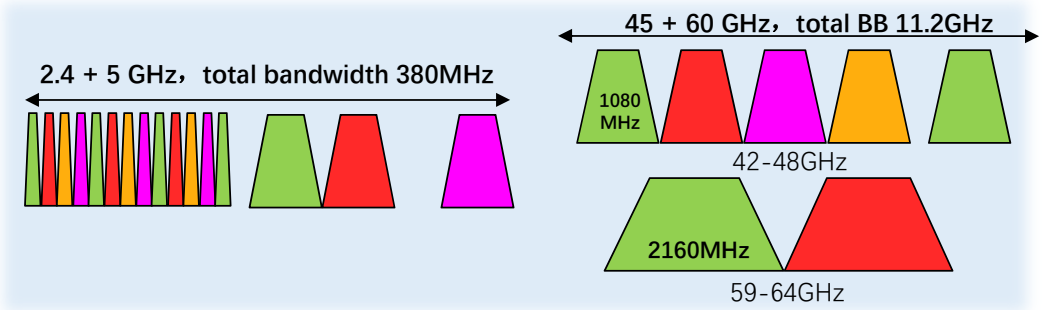
>10Gbps, with 11aj(45G) Wi-Fi

0
Perceptual delay

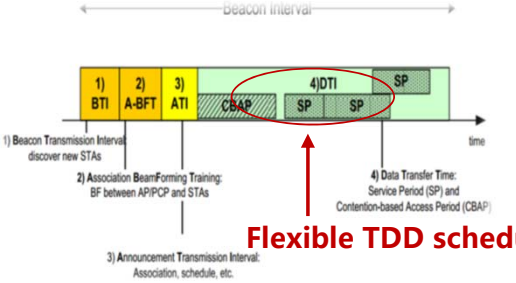
Low roaming delay
2s → 0.05s

FTTR + mmWave WiFi (Perfect Match)

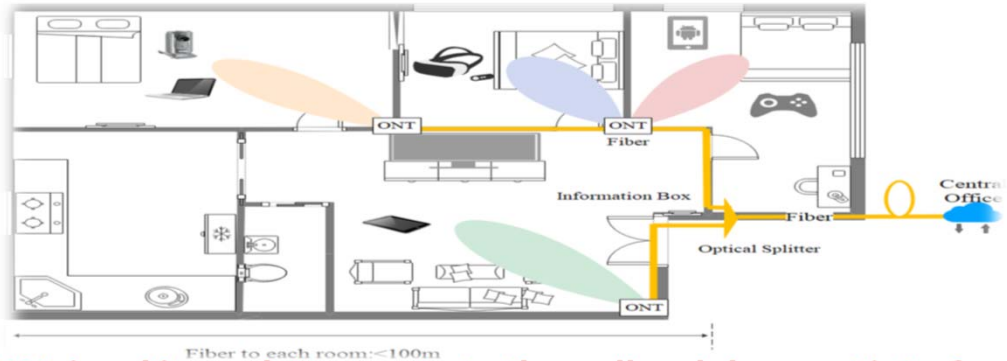
11aj(45G) mmW Wifi and FTTR are Perfect Match.



	Symbol length
802.11ac	3.6us
802.11ax	13.6us
802.11aj	484.4ns

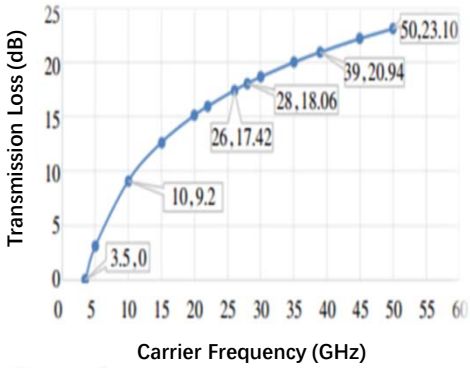


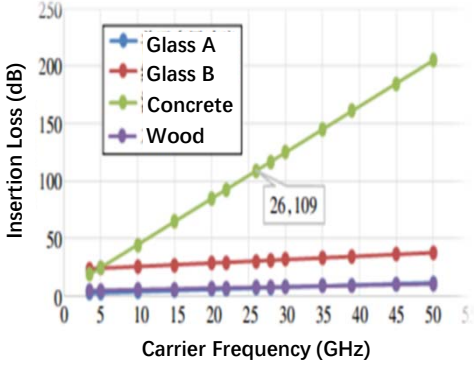
Sufficient mmW spectrum resources: mmW WiFi spectrum resources promulgated in China are nearly **30 times** that of sub-6GHz, and the data rate available with the same MIMO specification is nearly **7.5 times** that of sub-6GHz;



mmW signal is weak to penetrate the wall and does not interfere with each other: sub-6GHz signal propagation path includes reflection and transmission, and multipath is complex;

Lower delay: with increasing channel bandwidth, increasing symbol rate, each symbol becomes shorter, the schedulable granularity per unit time becomes finer, and the minimum delay reaches the order of x0 us





Security: the transmission and insertion loss through wall for mmW Wi-Fi signal is up to 200 dB. There is basically no signal leakage problem, and the security is higher.

FTTR + mmWave WiFi (Perfect Match)

FTTR + mmWave Wifi Economic and Social Impact

Cloud Game, cloud Office

Intelligent Manufacturing

High Density Access

Real-time Control

Cloud VR/AR

High precision navigation and positioning

- The massive growth of family business, communication, health and intelligence, and the demand for spectrum continues to increase;
- Industrial application explosion, large bandwidth communication, low delay control and centimeter level positioning;

Conclusion

① Q-band spectrum has been officially issued in China for indoor high-speed applications, and 42.3 ~ 48.4 GHz band is used without licensing.

② Based on the current situation of spectrum resources and technical architecture, IEEE 802.11aj (45 GHz) standard is likely to become the next generation ten Gbps WLAN standard in China.

③ With the rapid development of millimeter wave chips and digital processing chips based on silicon technology, millimeter wave WLAN will be widely used.

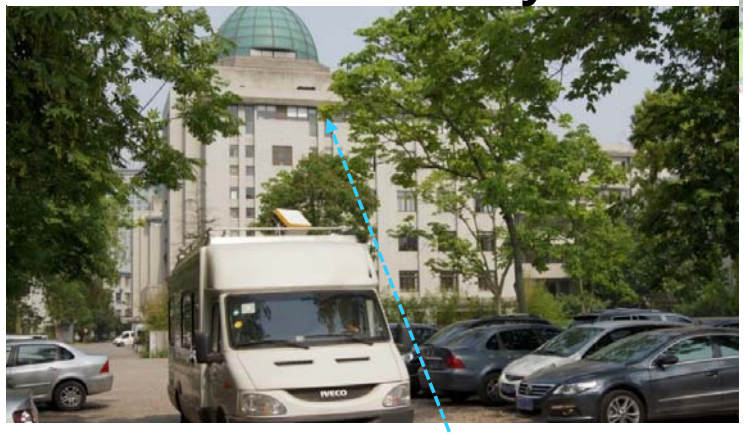
④ During the China "double Gigabit" development period, FTTR and 11aj mmW WiFi will form a perfect match, showing great advantages in high speed, low delay and non-interference aspects, and generating large scale economies and social benefits.

Thanks for Attention!

Jiulonghu Campus, Southeast Univ.

Wireless Valley

Wireless Valley Division, State Key Laboratory of millimeter waves



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