National Institute of Information and Communications Technology

テラヘルツシステム応用推進協議会 全体会合
2017年12月12日
「テラヘルツシステム標準化の最新動向」

IEEE 802.15.3d (100 Gbit/s Wireless) について

国立研究開発法人　情報通信研究機構
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Acknowledgements-1

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Acknowledgements-2

- The author would like to thank all members of the projects listed below
  - "R&D on Multi-ten gigabit wireless communication technology at sub-terahertz frequencies (FY2011-2015),"

  - "R&D on wireless transceiver systems with CMOS technology in 300GHz band (FY2014-2018)," and

  - "R&D on amplifier technology in 300 GHz band (FY2014-2017)."

IEEE Standard for High Data Rate Wireless Multi-Media Networks

Amendment 2: 100 Gb/s Wireless Switched Point-to-Point Physical Layer

IEEE Computer Society

IEEE Std 802.15.3d™-2017
(Amendment to
IEEE Std 802.15.3™-2016
as amended by
IEEE Std 802.15.3e™-2017)

IEEE Standard for High Data Rate Wireless Multi-Media Networks

Amendment 2: 100 Gb/s Wireless Switched Point-to-Point Physical Layer

Sponsor

LAN/MAN Standards Committee
of the
IEEE Computer Society

Approved 28 September 2017

IEEE-SA Standards Board

Participants

At the time of approval of this standard, the IEEE 802.15 Working Group had the following membership:

Robert F. Heile, *Working Group Chair*
Rick Alfvin, *Working Group Vice Chair*
Patrick Kinney, *Working Group Vice Chair, Working Group Secretary*
James P. K. Gilb, *Working Group Technical Editor*
Benjamin A. Rolfe, *Working Group Treasurer*

Thomas Kürner, Task Group 15.3d *Chair*
Iwao Hosako, Task Group 15.3d *Vice Chair*
Ken Hiraga, Task Group 15.3d *Secretary*
Monique B. Brown, Task Group 15.3d *Technical Editor*

Participants

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Abstract and Keywords

Abstract:

An alternative physical layer (PHY) at the lower THz frequency range between 252 GHz and 325 GHz for switched point-to-point links is defined in this amendment.

Two PHY modes are defined that enable data rates of up to 100 Gb/s using eight different bandwidths between 2.16 GHz and 69.12 GHz.

Keywords: 300 GHz, fixed point-to-point, IEEE 802.15.3™, IEEE 802.15.3d™, submillimeter waves, THz, wireless

Time-lines -1

Interest in developing a wireless communication system at THz frequencies started in 2008 with the establishment of the THz Interest Group.

In May 2014, Task Group 3d was formed, covering switched point to-point connections operating in the frequencies from 60 GHz up to the lower THz bands.

The Task Group started to work on four supporting documents: the Application Requirements Document, the Technical Requirements Document, the Channel Modeling Document, and the Evaluation Criteria Document.

In September 2014, discussions split the Task Group into two, leading to the development of an amendment for close proximity links at 60 GHz as the separate Task Group 3e.

The first meeting of Task Group 3e was in May 2015.

IEEE802.15.3e

10Gbpsを超える超高速近接無線通信の国際標準規格化を完了

- 瞬時の大容量データ送受信の実現によりIoT社会に貢献 -

2017.06.08 10:00
一般社団法人TransferJetコンソーシアム(所在地：東京都港区)は、そのプロモータ企業である4社「ソニー株式会社」「日本無線株式会社」「日本電信電話株式会社」「株式会社東芝」と協力し、米国に本部を持つ電気電子学会IEEEにて規格化活動を行い、10Gbpsを超える超高速近接無線通信IEEE802.15.3eの国際標準規格化を完了いたしました。なお、本活動に際し韓国ETRI(韓国電子通信研究院)のご協力を賜りました。本規格では、これまでのTransferJetのコンセプトを進化させ、あらゆる「かざす」機会を大容量データの瞬時転送の機会ととらえます。TransferJetの特徴である簡単な操作性を維持しつつ、10Gbpsを超える超高速通信で、4K解像度やバーチャルリアリティの映像といった大容量データを瞬時に転送します。また通信開始までの接続時間は2msec以下と大幅に短縮しました。これにより改札ゲート通過時のコンテンツ配信など、新たなユースケースの創出も検討しています。

IEEE802.15.3e

10Gbpsを超える超高速近接無線通信の国際標準規格化を完了

- 瞬時の大容量データ送受信の実現によりIoT社会に貢献 -

図1　歩きながら改札でタッチし瞬時にゲット

図2　KIOSK等でコンテンツ（アプリ・ソフト）を瞬時にダウンロード、もしくは個人の動画・画像を瞬時にアップロード

仕様
キャリア周波数 60GHz 帯
最大転送速度（SISO*） 13.1Gbps 256QAM
接続時間 2msec 以下
通信トポロジー 1 対1双方向
＊SISO: Single-Input, Single-Output

Time-lines -2

In November 2015, the required PAR change for Task Group 3d to limit the activities to the lower THz frequency ranges was approved.

During the March 2016 meeting, the supporting documents were approved and the call for proposals was issued.

Proposals were reviewed during the July and September 2016 meetings.

The group entered working group letter ballot in January 2017.

After one working group recirculation ballot, the sponsor ballot started in March 2017.

A total of two sponsor recirculation ballots were held, leading to approval of IEEE Std 802.15.3d-2017 by the IEEE-SA Standards Board on 28 September 2017.

Introduction

IEEE Std 802.15.3d-2017 is an amendment to IEEE Std 802.15.3-2016 that defines an alternative physical layer (PHY) at the lower THz frequency range, between 252 GHz and 325 GHz, for switched point-to-point links, along with the necessary MAC changes to support this PHY. This amendment builds on the concept of pairnet, introduced in IEEE Std 802.15.3e-2017, and inherits the corresponding MAC changes defined there.

Some of the key features and additions are as follows:

— Operation in the THz frequency band.

— Usage of eight different bandwidths between 2.16 GHz and 69.12 GHz.

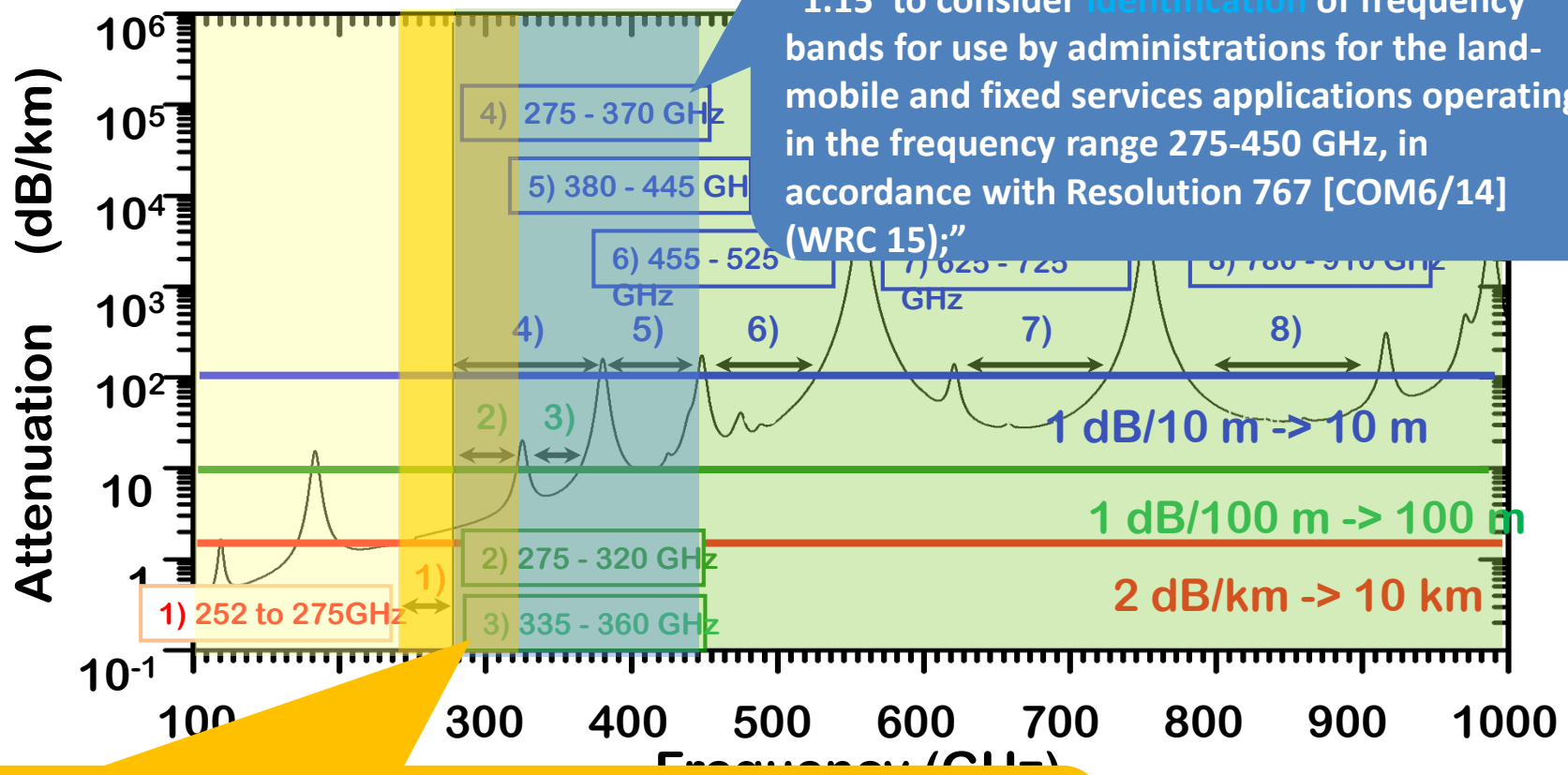
— Designed for data rates of up to 100 Gb/s.

— Use of a pairnet structure supporting wireless links for intra-device communication (e.g., board-to board communication), close proximity communication, wireless data centers, and backhaul/fronthaul links.

— Selectable PHY modes (single carrier and on-off keying) to achieve either ultra high-speed operation or system simplicity.

Possible Bands for Wireless communications in THz bands

+ All bands below 275 GHz are allocated.
+ Band between 252 and 275 GHz is allocated for land-mobile and fixed services.
+ Bands in the range from 275 to 1,000



WRC-2019 : A.I. 1.15

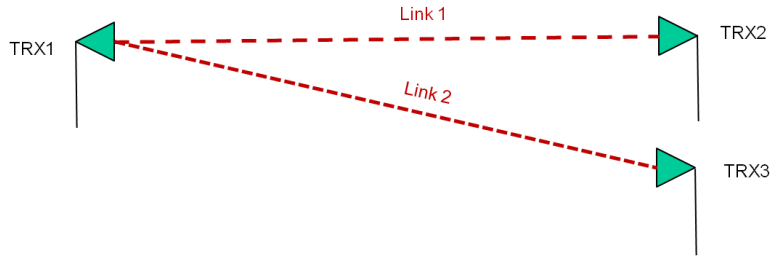
"1.15 to consider identification of frequency bands for use by administrations for the land-mobile and fixed services applications operating in the frequency range 275-450 GHz, in accordance with Resolution 767 [COM6/14] (WRC 15);"

PAR for P802.15.3d

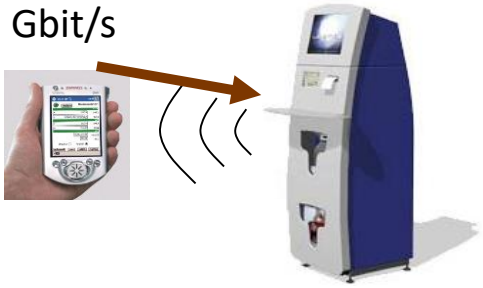
This amendment defines a wireless switched point-to-point physical layer to IEEE Std. 802.15.3 operating at a nominal PHY data rate of 100 Gbps with fallbacks to lower data rates as needed. Operation is considered in bands from 252 GHz up to and 325 GHz (BW=73GHz).

report of THz Tech. (Mar. 2009)

Applications for switched point-to-point links

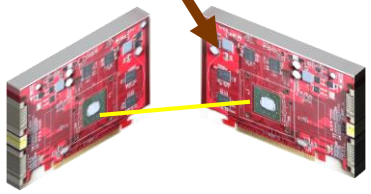


10...100 Gbit/s



Kiosk downloads

10...100 Gbit/s

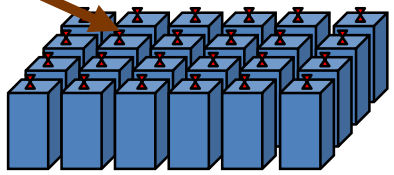


Intra-Device Communication

10..100 Gbit/s

Backhaul/Fronthaul links

10...100 Gbit/s



Wireless Links in Data Centers

4. General description

4.1a Pairnet

Change 4.1a as indicated:

A pairnet consists of at most two DEVs, as shown in Figure 4-0a. Typical communication distance is 10 cm or less for a pairnet DEV (PRDEV) with a high rate close proximity (HRCP) PHY. For a PRDEV with a THz PHY, typical communication distance is from a few centimeters up to several hundred meters. A PRDEV always connects as a pairnet.

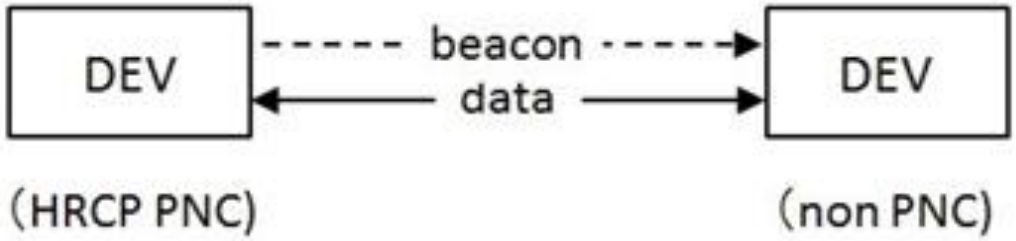


Figure 4-0a—IEEE 802.15.3 pairnet elements

4.2 Components of an IEEE 802.15.3 piconet

Change the fourth paragraph of 4.2 as indicated:

For HRCP PHYs and THz PHYs, the IEEE 802.15.3 piconet is not used.

IEEE 802.15.3 piconet

4.2 Components of an IEEE 802.15.3 piconet

An IEEE 802.15.3 piconet consists of several components, as shown in Figure 4-1. The basic component is the DEV. One DEV is required to assume the role of the piconet coordinator (PNC) of the piconet. The PNC provides the basic timing for the piconet with the beacon. Additionally, the PNC manages the quality of service (QoS) requirements, power save modes, and access control to the piconet.

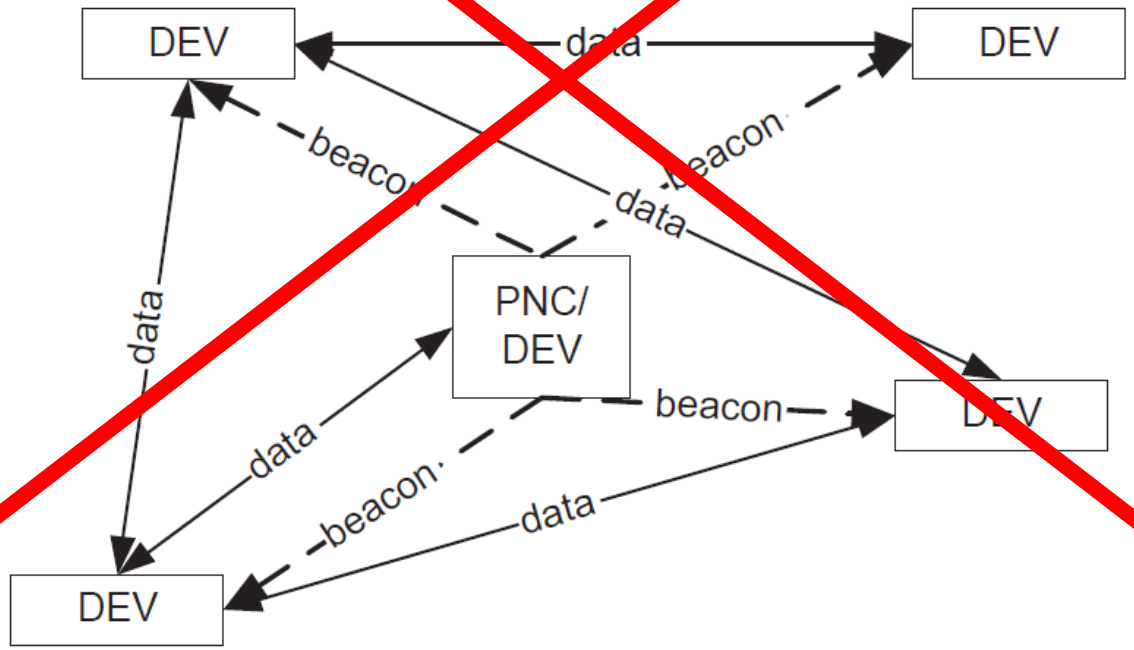
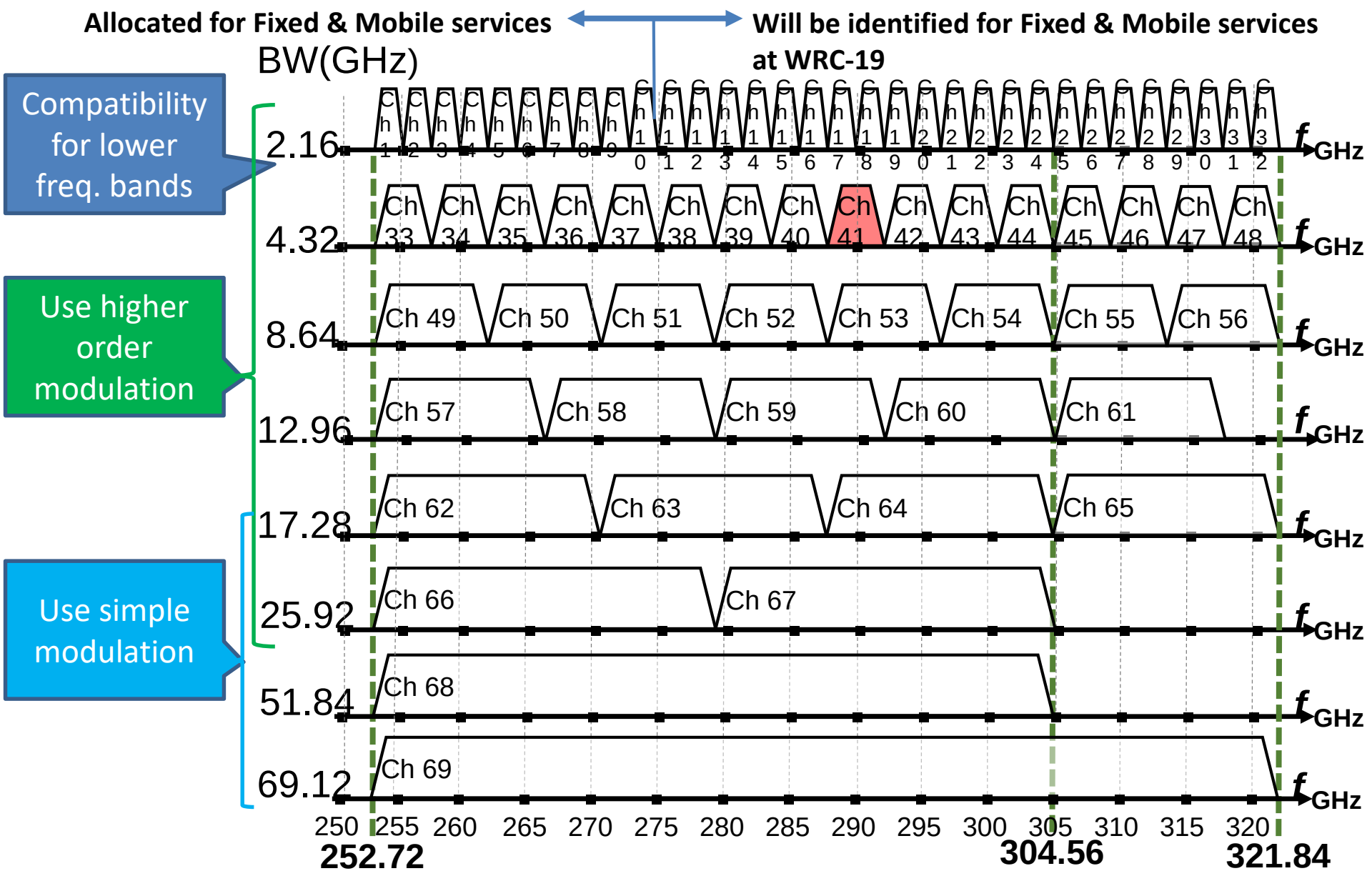


Figure 4-1—IEEE 802.15.3 piconet elements

Channel Plan (P802.15.3d)



The channel having CHNL_ID equal to 41 shall be defined as the default channel.

Possible Spectrum Parts based on FN 5.565 of the Radio Regulations

5.565 The following frequency bands in the range 275-1 000 GHz are identified for use by administrations for passive service applications:

– radio astronomy service: **275-323 GHz**, 327-371 GHz, 388-424 GHz, 426-442 GHz, 453-510 GHz, 623-711 GHz, 795-909 GHz and 926-945 GHz;

– Earth exploration-satellite service (passive) and space research service (passive): **275-286 GHz**, **296-306 GHz**, **313-356 GHz**, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz, 439-467 GHz, 477-502 GHz, 523-527 GHz, 538-581 GHz, 611-630 GHz, 634-654 GHz, 657-692 GHz, 713-718 GHz, 729-733 GHz, 750-754 GHz, 771-776 GHz, 823-846 GHz, 850-854 GHz, 857-862 GHz, 866-882 GHz, 905-928 GHz, 951-956 GHz, 968-973 GHz and 985-990 GHz.

The use of the range 275-1 000 GHz by the passive services does not preclude use of this range by active services. Administrations wishing to make frequencies in the 275-1 000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference until the date when the Table of Frequency Allocations is established in the above-mentioned 275-1 000 GHz frequency range.

All frequencies in the range 1 000-3 000 GHz may be used by both active and passive services. (WRC-12)

- In the frequency band 275-321 GHz the following bands do not have to be shared with EESS:
  - 286-296 GHz
  - 306-313 GHz

Channels marked as green do not overlap with EESS spectrum

Excerpt of the Channel Plan:

CHNL_ID	Bandwidth	Start frequency[a]	Center frequency	Stop frequency[a]
15	2.16	282.96	284.04	285.12
16	2.16	285.12	286.2	287.28
17	2.16	287.28	288.36	289.44
18	2.16	289.44	290.52	291.6
19	2.16	291.6	292.68	293.76
20	2.16	293.76	294.84	295.92
21	2.16	295.92	297	298.08
26	2.16	306.72	307.8	308.88
27	2.16	308.88	309.96	311.04
40	4.32	282.96	285.12	287.28
41	4.32	287.28	289.44	291.6
42	4.32	291.6	293.76	295.92
43	4.32	295.92	298.08	300.24
52	8.64	278.64	282.96	287.28
53	8.64	287.28	291.6	295.92
54	8.64	295.92	300.24	304.56

13.2 THz-SC PHY

The THz-SC PHY is designed for extremely high PHY-SAP payload bit rates of 100 Gb/s using multiple bandwidths. Higher data rates are achievable, depending on the combination of modulation, bandwidth, and coding.

Modulation

- π/2-shift BPSK, π/2-shift QPSK
- π/2-8-PSK, π/2-8-APSK
- 16 QAM, 64 QAM

FEC

Supporting the following two LDPC codes is mandatory for the THz-SC PHY:
a rate-14/15 LDPC(1440,1344) code, and a rate-11/15 LDPC(1440,1056) code.

13.3 THz-OOK PHY

The THz-OOK PHY is designed for cost-effective devices that require low power, low complexity, and simple design. For applications using this PHY, transmission ranges of a few tens of centimeters are targeted. The THz-OOK PHY is designed for PHY-SAP payload-bit rates between 1.3 Gb/s, using a single channel with a bandwidth of 2.16 GHz, and the maximum 52.6 Gb/s, using a bandwidth of 69.12 GHz.

Modulation

- OOK

FEC

The FEC scheme is specified by a (240,224)-Reed Solomon code and two LDPC codes with code rates of 14/15 and 11/15. The Reed Solomon Code is mandatory for the THz OOK-PHY.
The LDPC (1440,1344) and the LDPC (1440,1056) are both optional for the THz-OOK PHY.

Table 13-4—MCS dependent parameters for the THz-SC PHY

MCS identifier	Modulation	FEC rate	Bandwidth 2.16 GHz		Bandwidth 4.32 GHz		Bandwidth 8.64 GHz		Bandwidth 12.96 GHz		Bandwidth 17.28 GHz		Bandwidth 25.92 GHz		Bandwidth 51.84 GHz		Bandwidth 69.12 GHz	
			Data rate (Gb/s)		Data rate (Gb/s)		Data rate (Gb/s)		Data rate (Gb/s)		Data rate (Gb/s)		Data rate (Gb/s)		Data rate (Gb/s)		Data rate (Gb/s)	
			without PW	with PW	without PW	with PW	without PW	with PW	without PW	with PW	without PW	with PW	without PW	with PW	without PW	with PW	without PW	with PW
0	BPSK	11/15	1.29	1.13	2.58	2.26	5.16	4.52	7.74	6.78	10.33	9.04	15.49	13.55	30.98	27.11	41.30	36.14
1	BPSK	14/15	1.64	1.44	3.29	2.87	6.57	5.75	9.86	8.62	13.14	11.50	19.71	17.25	39.42	34.50	52.56	45.99
2	QPSK	11/15	2.58	2.26	5.16	4.52	10.33	9.03	15.49	13.55	20.65	18.07	30.98	27.10	61.95	54.21	82.60	72.28
3	QPSK	14/15	3.29	2.87	6.57	5.75	13.14	11.50	19.71	17.25	26.28	23.00	39.42	34.50	78.85	68.99	105.13	91.99
4	8-PSK	11/15	3.87	3.39	7.74	6.78	15.49	13.55	23.23	20.33	30.98	27.11	46.47	40.66	92.93	81.32	123.91	108.42
5	8-PSK	14/15	4.93	4.31	9.86	8.62	19.71	17.25	29.57	25.87	39.42	34.50	59.13	51.74	118.27	103.49	157.69	137.98
6	8-APSK	11/15	3.87	3.39	7.74	6.78	15.49	13.55	23.23	20.33	30.98	27.11	46.47	40.66	92.93	81.32	123.91	108.42
7	8-APSK	14/15	4.93	4.31	9.86	8.62	19.71	17.25	29.57	25.87	39.42	34.50	59.13	51.74	118.27	103.49	157.69	137.98
8	16-QAM	11/15	5.16	4.52	10.33	9.03	20.65	18.07	30.98	27.10	41.30	36.14	61.95	54.21	123.90	108.42	165.21	144.55
9	16-QAM	14/15	6.57	5.75	13.14	11.50	26.28	23.00	39.42	34.50	52.57	45.99	78.85	68.99	157.70	137.98	210.26	183.98
10	64-QAM	11/15	7.74	6.78	15.49	13.55	30.98	27.10	46.46	40.66	61.95	54.21	92.93	81.31	185.86	162.62	247.81	216.83
11	64-QAM	14/15	9.86	8.62	19.71	17.25	39.42	34.50	59.14	51.74	78.85	68.99	118.27	103.49	236.54	206.98	315.39	275.97

THz-OOK PHY

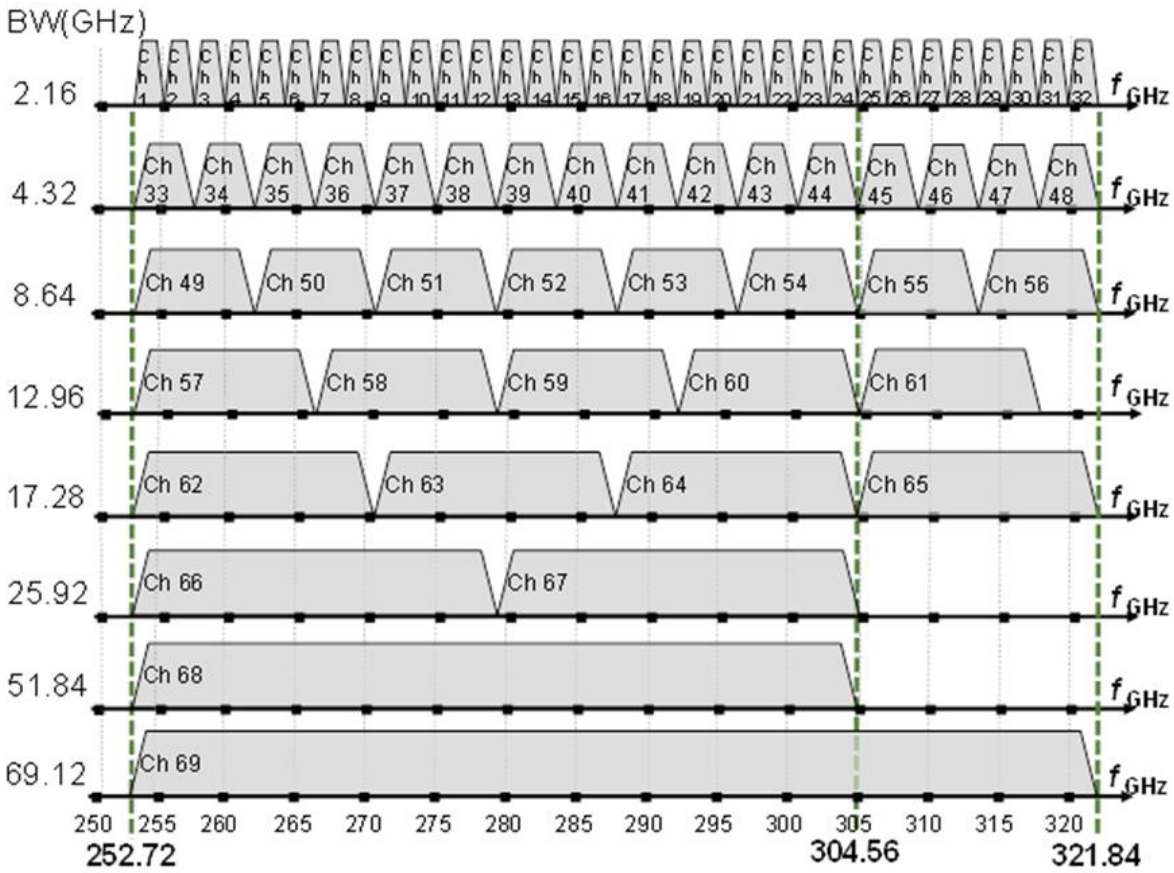
Table 13-12—MCS dependent parameters for the THz-OOK PHY

MCS identifier	Bandwidth (GHz)	FEC rate	Data rate (Gb/s) with PW	Data rate (Gb/s) without PW
0	2.16	224/240	1.64	1.44
0	4.32	224/240	3.29	2.87
0	8.64	224/240	6.57	5.75
0	12.96	224/240	9.86	8.62
0	17.28	224/240	13.14	11.50
0	25.92	224/240	19.71	17.25
0	51.84	224/240	39.42	34.50
0	69.12	224/240	59.14	51.74
1	2.16	11/15	1.29	1.29
1	4.32	11/15	2.58	2.26

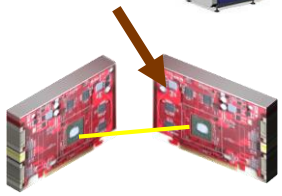
ble 13-12—MCS dependent parameters for the THz-OOK PHY *(continued)*

MCS identifier	Bandwidth (GHz)	FEC rate	Data rate (Gb/s) with PW	Data rate (Gb/s) without PW
1	8.64	11/15	5.16	4.52
1	12.96	11/15	7.74	6.78
1	17.28	11/15	10.33	9.04
1	25.92	11/15	15.49	13.55
1	51.84	11/15	30.98	27.11
1	69.12	11/15	41.30	36.14
2	2.16	14/15	1.64	1.44
2	4.32	14/15	3.29	2.87
2	8.64	14/15	6.57	5.75
2	12.96	14/15	9.86	8.62
2	17.28	14/15	13.14	11.50
2	25.92	14/15	19.71	17.25
2	51.84	14/15	39.42	34.50
2	69.12	14/15	52.56	45.99

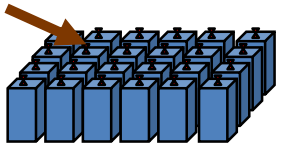
Summary: Key facts of IEEE P802.15.3d



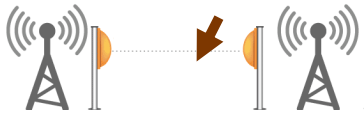
Kiosk DL



Intra-Device Communication



Wireless Links in Data Centers



Backhaul/Fronthaul links

- Pairnet (IEEE802.15.3e)
- Switched point-to-point link (KIOSK-DL, Intra-Device, Data Center, F/B-haul)
- 2 PHY-modes (THz-SC PHY, THz-OOK-PHY) with 7 modulation schemes
  - BPSK, QPSK, 8-PSK, 8-APSK, 16-QAM, 64 QAM, OOK
- 3 channel coding schemes (14/15-rate LDPC (1440,1344), 11/14-rate LDPC (1440,1056), 11/14-rate RS(240,224)-code)
- The channel having CHNL_ID equal to 41 shall be defined as the default channel.