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IEEE 802.15.3d and other activities related to THz Communications. Where to go next?

Towards Terahertz Communications Workshop, European Commission, 7 March 2018

Thomas Kürner, Sebastian Rey

Scope of this Talk

- This presentation is intended to provide very brief information on ongoing and completed activities in standardisation and regulation for THz Communications
- Standardisation at IEEE 802:
 - A first standard for frequencies in the bands 252 to 275 GHz has been published
 - Work continues in IEEE 802.15 Interest Group THz
 - Both activities have been lead by Thomas Kürner (TU Braunschweig) as Chair of IEEE 802.15 TG3d and IEEE 802.15 IG THz
- Regulation (WRC 2019):
 - At the upcoming WRC the frequency band between 275 GHz and 450 GHz is considered by a specific agenda item AI 1.15 for land-mobile and fixed services
 - Regulators are currently in the preparatory phase
 - Coordinator for AI 1.15 in Germany and Europe (CEPT) is Sebastian Rey (TU Braunschweig)

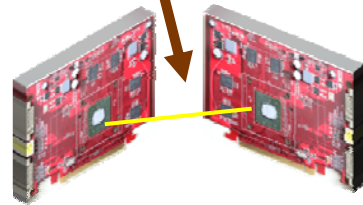
Standardisation Activities @ IEEE 802

- The first project within IEEE 802 towards 100 Gbps has been approved in March 2014:
Task Group IEEE 802.15.3d
- Scope of the project: „*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 to 325 GHz** at ranges as short as a few centimeters and up to several 100m. Additionally, modifications to the Medium Access Control (MAC) layer, needed to support this new physical layer, are defined.*”
- Targeted applications:
 - Kiosk Downloading
 - Intra-Device Communication
 - Wireless Backhauling/Fronthauling
 - Additional Wireless Links in Data Centers
- The standard IEEE 802.15.3d-2017 has been approved on 28th September 2017 and published on 12th October 2018 as the **worldwide first wireless communications standard operating at the 300 GHz** frequency range



Applications targeted by IEEE 802.15.3d-2017

10...100
Gbit/s



Intra-Device
Communication

10...20
Gbit/s



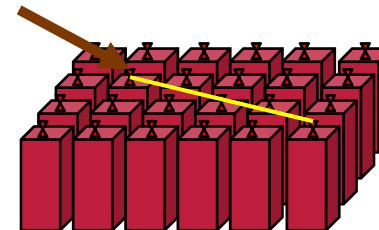
Kiosk downloads

10..100
Gbit/s



Backhaul/Fronthaul links

10...100 Gbit/s



Additional Wireless
Links in Data Centers

See also: "Applications Requirement Document (ARD)", DCN: 15-14-0304-16-003d, IEEE 802.15 TG3d, May 2015,
<https://mentor.ieee.org/802.15/documents>



Key facts of IEEE 802.15.3d

- New PHY for Std. IEEE 802.15.3-2016
- MAC is mainly based on IEEE 802.15.3e-2017, which introduced the concept of „Pairnet“
 - **Point-to-point nature with highly-directive antennas** reduces the problem of interference and „fighting for access“
 - Positions of Tx and Rx antennas are known
- 8 different channel bandwidths (as multiples of 2.16 GHz)
- 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.

IEEE STANDARDS ASSOCIATION



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

Sponsored by the
LAN/MAN Standards Committee

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

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



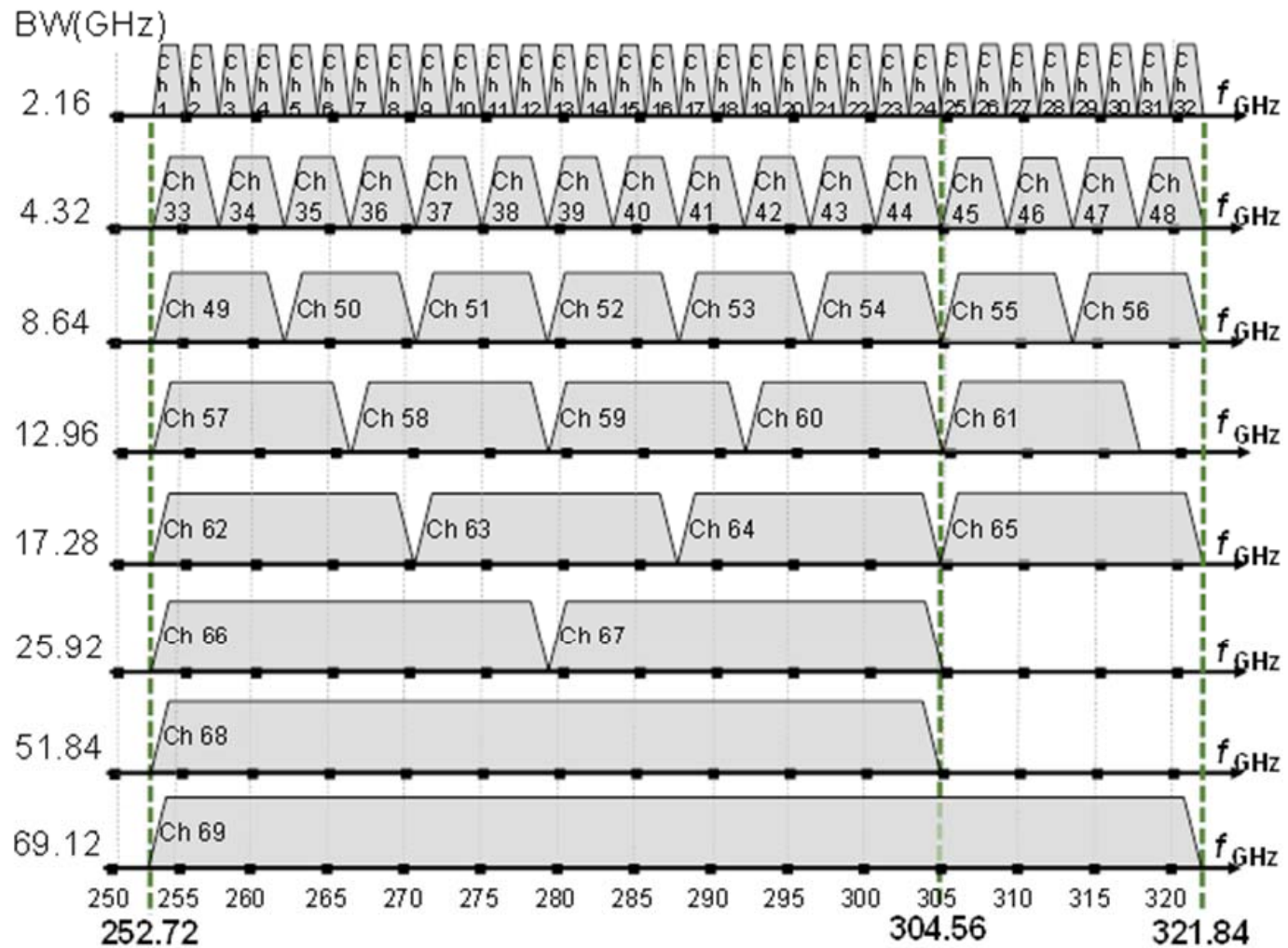
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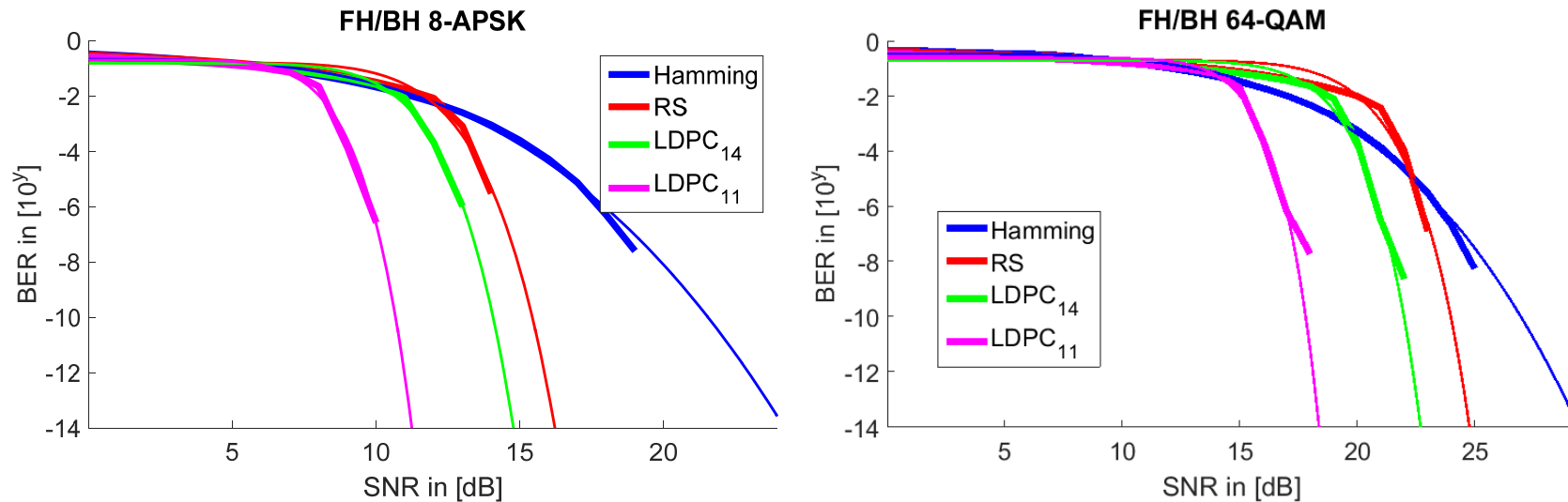
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IEEE 802.15.3d Channel Plan



System Evaluation

Exemplary Results for the Backhaul/Fronthaul Application



- Link Level Simulations have been performed for all modulation and coding schemes
=> target Signal to Noise Ratio (SNR) for a required Bit Error Ratio (BER) of 10^{-12}
- Link budget analysis for all bandwidths
- Assumptions:
 - Transmitter output power of 1 W
 - Antenna gain of 40 dBi at both ends of the link

Achievable Link Distances and Data Rates for the Backhaul/Fronthaul Application

Assumption of a margin of 20 dB for atmospheric attenuation

MCS Identifier	Modulation	FEC Rate	Maximum Link Distance in m							
			2.16 GHz	4.32 GHz	8.64 GHz	12.96 GHz	17.28 GHz	25.92 GHz	51.84 GHz	69.12 GHz
0	BPSK	11/15	5343	3778	2671	2181	1889	1542	1091	944
1	BPSK	14/15	3646	2578	1823	1488	1289	1052	744	644
2	QPSK	11/15	3796	2684	1898	1550	1342	1096	775	671
3	QPSK	14/15	2563	1812	1282	1046	906	740	523	453
4	8-PSK	11/15	2157	1525	1078	880	762	623	440	381
5	8-PSK	14/15	1725	1220	862	704	610	498	352	305
6	8-APSK	11/15	2157	1525	1078	880	762	623	440	381
7	8-APSK	14/15	1729	1223	864	706	611	499	353	306
8	16-QAM	11/15	1709	1209	855	698	604	493	349	302
9	16-QAM	14/15	1152	814	576	470	407	332	235	204
10	64-QAM	11/15	949	671	475	387	336	274	194	168
11	64-QAM	14/15	581	411	291	237	205	168	119	103

Data rate > 50 Gbit/s

Data rate > 100 Gbit/s

What is next in Standardisation?

IEEE 802.15 Interest Group THz

- The Interest Group THz (IG THz) has been established already in 2008
- The focus of the Interest Group is primarily concerned with THz communications and related network applications operating in the THz frequency bands between 275 and 3000 GHz.
- IEEE 802.15 TG 3d was a spin-off from this Interest Group.
- Currently the IG THz
 - is monitoring the progress in the area of THz communications in regard to the possibility of establishing future Study Groups **with applications different from the scope of Std. IEEE 802.15.3d-2017**, for example WLAN-type of applications requiring beam steering or advanced methods for device discovery.
 - is interacting in the WRC 2019 process e.g. by participation in drafting liaison statements between IEEE 802 and ITU-R.
 - May trigger a further amendment of the standard depending on the outcome of WRC 2019
- Next meeting during the IEEE 802 Wireless Interim Session (Warsaw, 7-11 May 2018)

Starting point for Radio Regulations: Outcome of WRC 2012

5.565 A number of bands in the frequency range 275-1 000 GHz are identified for use by administrations for passive service applications. The following specific frequency bands are identified for measurements by passive services:

- 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)

Why is sharing necessary at all?

- Assuming, that interference to Radio Astronomy can be handled (operated in very high remote areas only!) the most critical passive service wrt THz Communication is Earth Exploration Satellite Service (EESS):
 - Transmission in remaining bands only would allow
 - small bandwidths
 - distributed over entire THz range

Not feasible for data rates $\gg 10$ Gbit/s

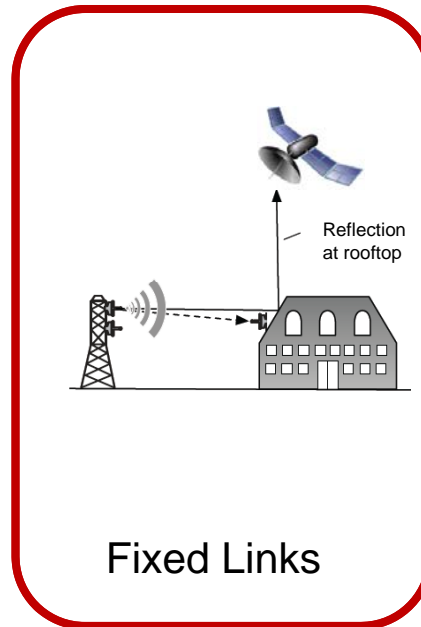
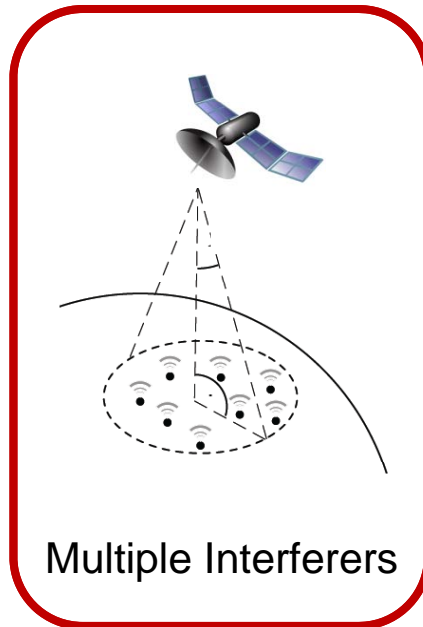
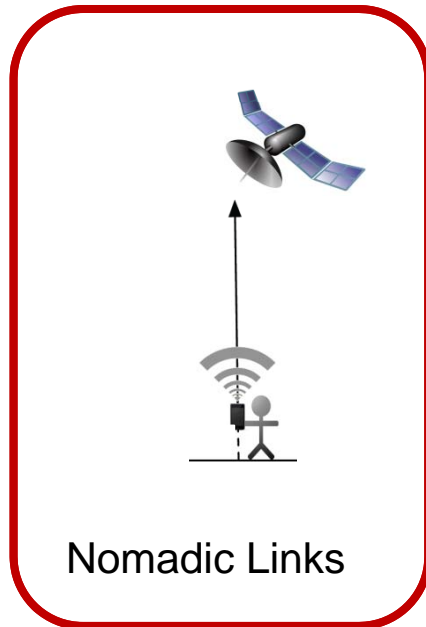
- Coexistent spectrum usage

Interference investigations inevitable to have a safe basis for the operation of THz Communications

Remaining Frequency Bands not used by EESS	Total available Bandwidth
286-294 GHz	8 GHz
307-313 GHz	6 GHz
356-361 GHz	5 GHz
366-369 GHz	3 GHz
392-397 GHz	5 GHz
399-409 GHz	10 GHz
411-416 GHz	5 GHz
434-439 GHz	5 GHz



Possible Interference Scenarios to be studied



- Interference Mitigation has to be considered right from the beginning, when developing THz Communications Systems

S. Priebe et al. „Interference Investigations of Active Communications and Passive Earth Exploration Services in the THz Frequency Range“, IEEE Transactions on THz Science and Technology, vol. 2, no. 5, pp. 525-537, 2012



The use of the frequency band 275 to 450 GHz for mobile and fixed services is subject to WRC 2019 AI 1.15

WRC 2015 agreed in resolution 767:

- to have an agenda item for WRC 2019 to consider **identification of spectrum for land-mobile and fixed active services in the range of 275 GHz to 450 GHz** while maintaining protection of the passive services identified in the existing footnote 5.565.
- ITU-R is invited to
 - identify technical and operational characteristics (WP 5A and 5C for the new active services, WP 7C and 7D for existing passive services)
 - study spectrum needs (WP 5A and 5C)
 - develop propagation models (SG 3)
 - conduct sharing studies with the passive services (WP 1A)
 - identify candidate frequency bands (WP 1A)
- ITU-R WP1A is leading the preparation of AI 1.15 and conducting the sharing studies.



Current status of the preparatory work of AI 1.15 WRC 2019

- The supporting Working Parties (WPs 5A, 5C, 7C, 7D and SG3) have finished their tasks.
- Regarding the new active services the reports ITU-R F.2416 and ITU-R M.2417 have been published. The applications are **Close Proximity/Kiosk Downloading, Intra-Device Communications and additional wireless links in data centers (land mobile) and wireless front-/backhaul links (fixed services)**.
- The frequency bands of interest are
 - between 275 to 450 GHz for land mobile applications.
 - especially, 275-325 GHz and 380-445 GHz for fixed service applications (maybe another band is possible in between).
- WP 1A is conducting sharing studies and preliminary study results are available.
 - **For instances in the band 275 to 296 GHz** coexistence with the passive services seems to be possible. This provides a **continues bandwidth of 44 GHz** with the existing bands from 252-275 GHz.
 - Other bands are under consideration.
- Next and final meeting of WP 1A is in June 2018.

Contact Data:

Prof. Dr.-Ing. Thomas Kürner
Dipl.-Ing. Sebastian Rey
Institut für Nachrichtentechnik
Technische Universität Braunschweig
Schleinitzstr. 22
D-38092 Braunschweig

Tel.: +49 531 391 - 2416 (Kürner) -2439 (Rey)

Fax: +49 531 391 5192

E-Mail: t.kuerner@tu-bs.de; rey@ifn.ing.tu-bs.de

<http://www.ifn.ing.tu-bs.de>



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