LTE Direct Trial

White Paper

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1 Introduction

LTE Direct is a new and innovative device-to-device technology that enables discovering thousands of devices and their services in the proximity of ~500m, in a privacy-sensitive and battery-efficient way. This allows the discovery to be always on and autonomous without drastically reducing the device battery life. This distinguishes LTE Direct from other proximity solutions such as OTT-based options that use GPS, or BT-LE, Wi-Fi Direct, and Wi-Fi Aware.

In addition, the common language enabled via the LTE Direct expression name space framework enables discovery across applications. This horizontal discovery opens up a much broader network to app developers and users who do not need specific applications to receive value.

LTE Direct uses licensed spectrum, allowing mobile operators to employ it as a way to offer a range of differentiated applications and services to users. It relies on the LTE physical layer to provide a scalable and universal framework for discovery and for connecting proximate peers. LTE Direct is standardized as part of the Proximity Services (ProSe) feature in 3GPP Release 12. The system architecture definition is complete. The RAN specification and ASN.1 is expected to be complete by March 2015. RF performance and conformance is expected to be complete by June 2015.

This white paper presents the results of the LTE Direct technical trial conducted jointly in Bonn, Germany, by Deutsche Telekom, Huawei, and Qualcomm® in September 2014. The trial was aimed at testing the discovery performance of LTE Direct pre-standards implementation on Qualcomm prototype devices and Huawei infrastructure.

The tests during the trial covered the following aspects of LTE Direct discovery performance:

- Outdoor and Indoor
- High-mobility scenarios
- Comparison with Wi-Fi Direct

The tests showed the high discovery range of LTE Direct in the above conditions. Table 1 summarizes the discovery performance between LTE Direct and Wi-Fi in Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) conditions. The discovery range observed in the trial was also observed in Qualcomm simulations (see Appendix).

Table 1 Wi-Fi Direct vs LTE Direct discovery range

	Rural LOS	**Urban LOS**	**Urban NLOS**
Wi-Fi Direct (2.4 GHz)	200m	150m	30m
LTE Direct (2.6 GHz	550m	350m	170m

Wi-Fi Aware is a recent proximate discovery feature of Wi-Fi. It has the same underlying physical layer and link budget as Wi-Fi Direct and exhibits the same Wi-Fi direct discovery range in the above scenarios.

Mobility tests showed no impact to the LTE Direct discovery in rural (speeds up to 120 km/h) and urban (speeds up to 30 km/h NLOS and 50 km/h LOS) scenarios.

The trials showed the enhanced discovery performance of LTE Direct in terms of higher discovery range and reliability compared to Wi-Fi Direct.

2 Bonn trial network overview

This section covers the RAN and core network configuration.

2.1 Network configuration

The trial was run in the area around DT Bonn offices at Landgrabenweg and Friedrich-Ebert-Allee. The trial network consisted of three outdoor sites and one indoor site. It was conducted using a TDD LTE network system deployed at 2.6 GHz with 5 MHz bandwidth. Time synchronization between eNBs was ensured by means of GPS. The trial area is shown in Figure 1. The heat map in the figure shows the received power strength from serving eNBs across the whole area.

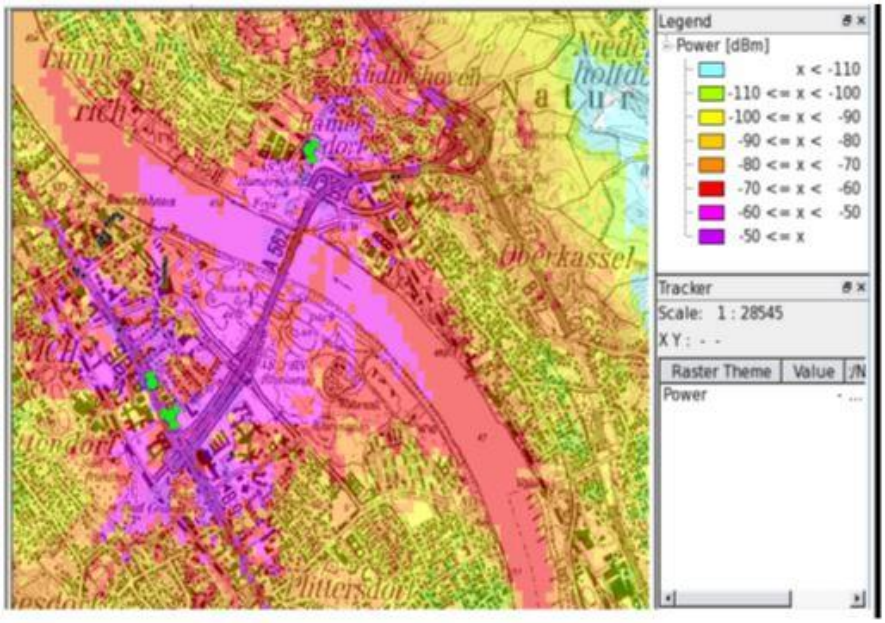


Figure 1: Bonn trial network area

Huawei provided TDD eNBs with support for a newly defined SIB 17 information block that is broadcast to indicate discovery subframes to the LTE Direct devices. The scheduler was also updated to ensure that no uplink data traffic was scheduled during the discovery subframes. The eNBs were synchronized to each other using GPS.

The UEs were Qualcomm prototype MSM8974 devices with trial firmware implementing the pre-standard version of LTE Direct. The prototype implementation used a single resource block for the discovery signal transmission instead of 2 Resource Blocks (RB) as defined in 3GPP Release 12 standard.[1]

[1] *It is reasonable to assume no significant difference in discovery range between the prototype 1 RB implementation and a standards compliant 2 RB implementation. Spreading the Tx power over 2 RBs results in a 3 dB link budget reduction. This is partially offset by better coding across the 2 RBs, resulting in total link budget reduction of 1-2 dB. Moreover, transmission over 2 RBs also allows for significantly larger discovery payload, i.e., 184 bits instead of 128 bits.*

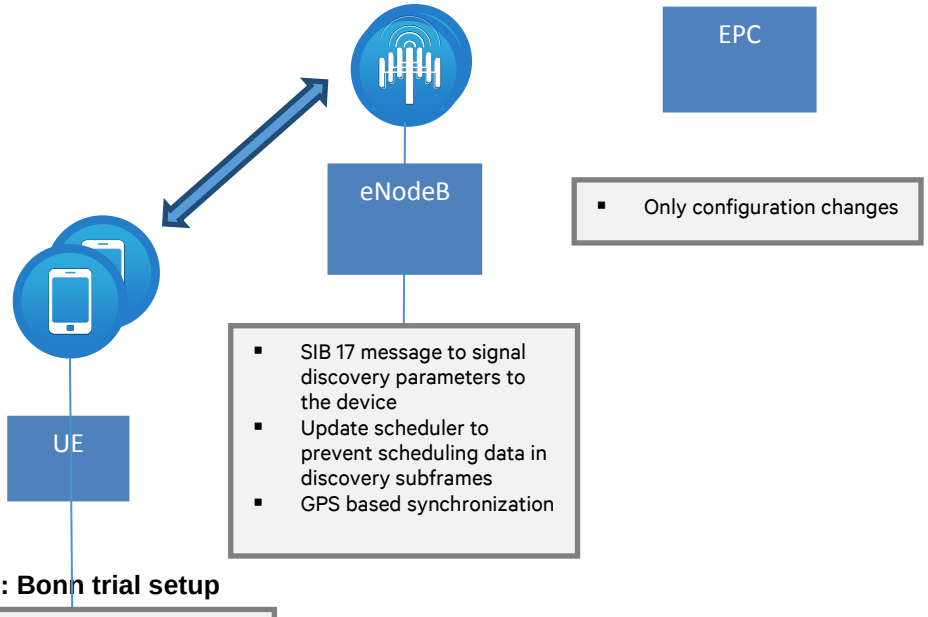


Figure 2: Bonn trial setup

llocation configuration as shown in Figure 3 was 32 subframes every 2.56 sec. here the allocation was different and these are called out in the next section. UL/DL TDD frame configuration 1 was used.

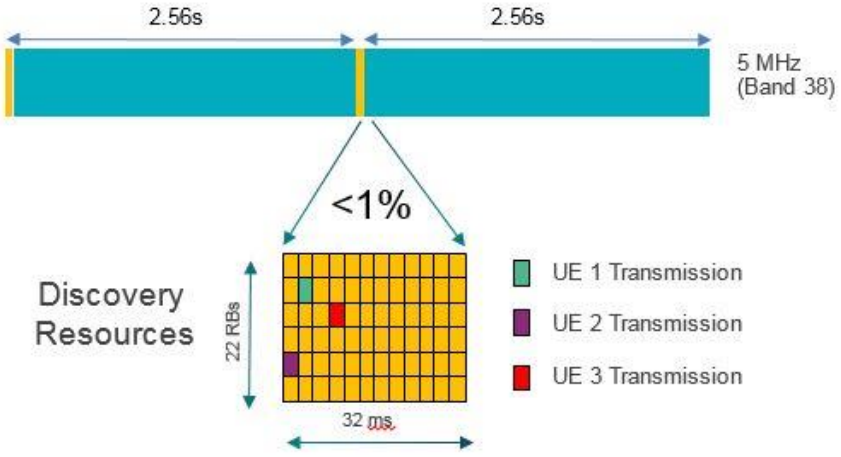


Figure 3: Default Discovery Resource allocation configuration

3 Trial results

One of the key benefits of LTE Direct is the large discovery range. The tests during the trial focused on the discovery range under the following scenarios:

- Outdoor
- Indoor
- High mobility
- Comparison with Wi-Fi Direct

The discovery range was measured based on decoding probability of 20%.

3.1 Outdoor

The outdoor scenarios tested were rural LOS, urban LOS and urban NLOS

3.1.1 Rural LOS

The rural LOS tests were executed in a park along the river in the Landgrabenweg area. The announcing UE was located at one end under a bridge and the subscribing UEs were located at different locations on the same side of the river, as shown in Figure 4. The discovery range was measured based on acceptable probability of decoding the same side of the river, as shown in Figure 4. The maximum measured discovery range was 550m[2].

Figure 4: Rural LOS scenario

[2] *Discovery range of 1500m was observed when having a body of water between UEs and with announcing UE at higher elevation.*

3.1.2 Outdoor Urban LOS

The urban LOS tests were executed near the Deutsche Telekom offices on Friedrich-Ebert-Allee. The announcing UEs were at one end of the office and the subscribing UEs were at different locations on the same side of the street, as indicated in Figure 5. This scenario included real obstacles like trees and cars which impacted the discovery range. The measured discovery range in this scenario was up to 350m.

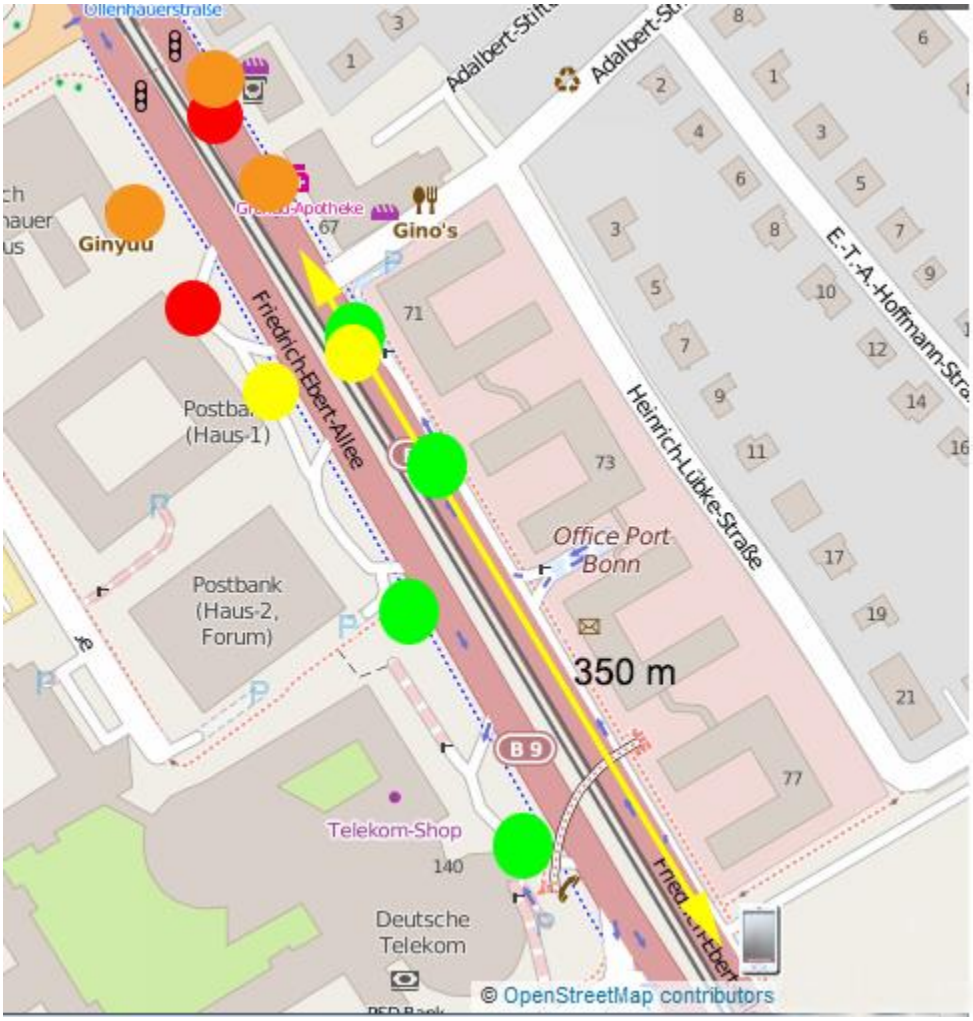


Figure 5: Urban LOS scenario

3.1.3 Outdoor Urban NLOS

The urban NLOS tests were conducted with one announcing UE and multiple subscribing UEs at various NLOS locations as shown in Figure 6. The measured discovery range in this scenario was 170m.

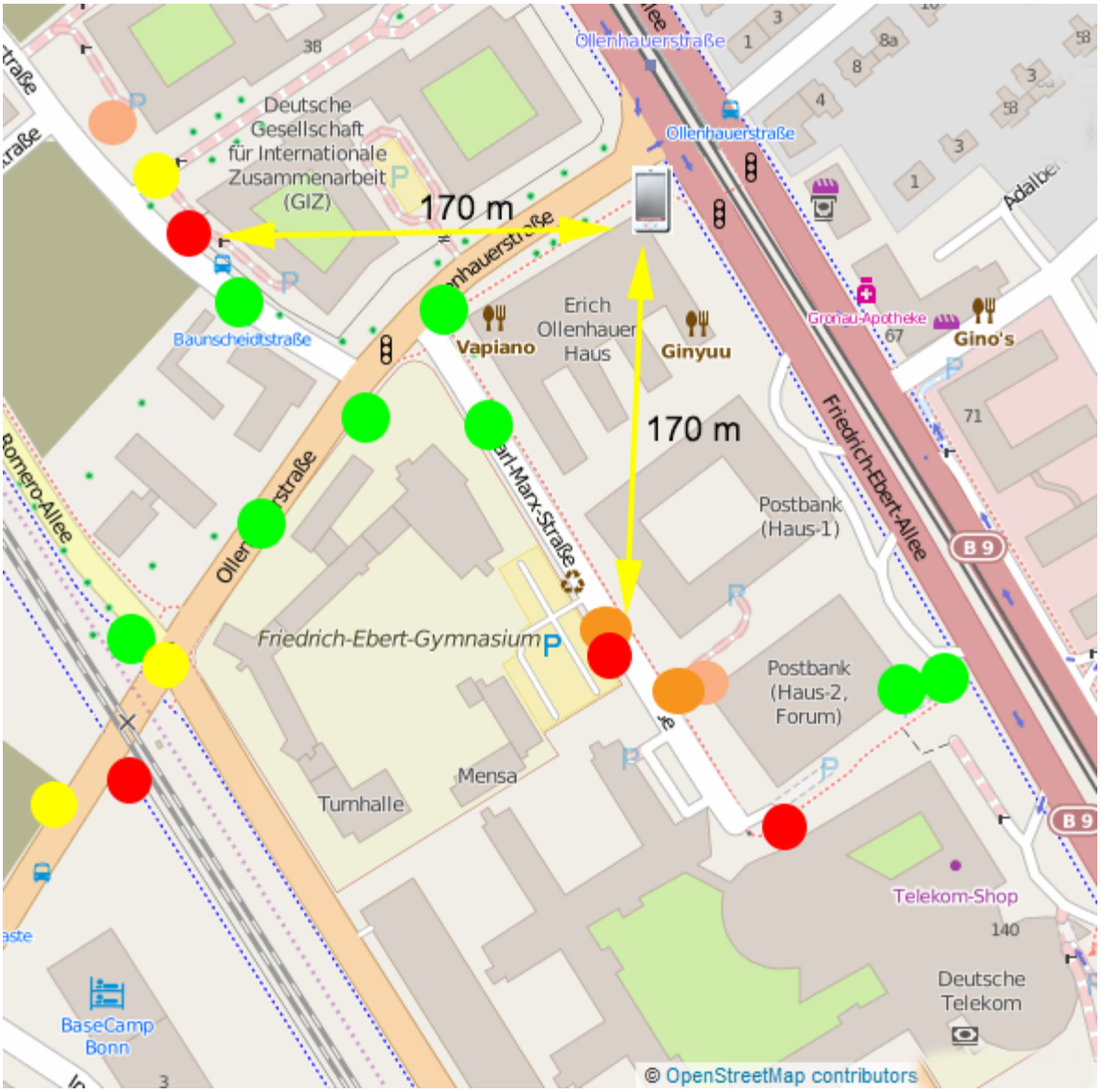


Figure 6: Urban NLOS scenario

3.2 Indoor

The indoor tests covered LOS and NLOS scenarios. These test were conducted in various locations within Deutsche Telekom offices.

3.2.1 Indoor LOS

Testing for this scenario was limited since the longest LOS distance available indoors was 140m. The maximum discovery range could be much larger than this distance.

3.2.2 Indoor NLOS

Indoor NLOS tests were done with a single corner scenario and with 2 corner scenarios. The conditions depend very much on the material and the number of walls and hallways between the announcing and monitoring UE.

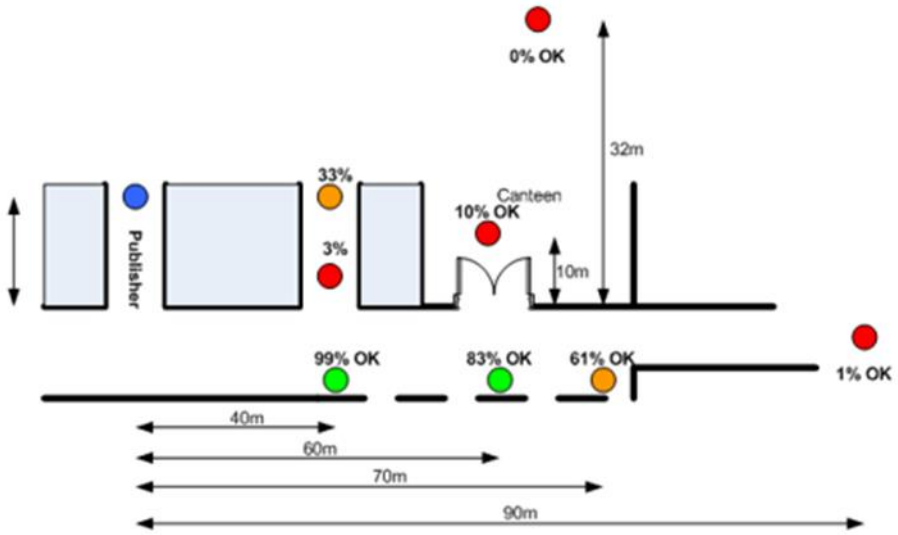


Figure 7: Indoor NLOS scenario

3.2.3 Indoor-to-outdoor NLOS

In this test the announcing UE was placed deep inside the third floor of the DT office building and the monitoring UEs were outside the building on the ground floor. As can be seen from Figure 8, the transmission traversed multiples walls and floors. The observed discovery distance observed was 65m. For practical discovery scenarios, it is recommended that the announcing UE be placed as close to the outside wall as possible to maximize discovery distance in these scenarios.

Figure 8: Indoor-to-outdoor NLOS scenario

3.3 High-speed mobility

These tests were conducted to observe the performance of TE Direct in high-speed mobility scenarios.

3.3.1 Rural scenario

These tests were run on a highway with 3 publishers placed 800m apart and the announcing UE in a vehicle that traveled along the route as shown in Figure 9. The speed of the vehicle varied between 60 km/h and 120 km/h on this route. A discovery range of almost 1 km was observed in LOS conditions when announcing UEs were placed high above the ground compared to monitoring UEs.

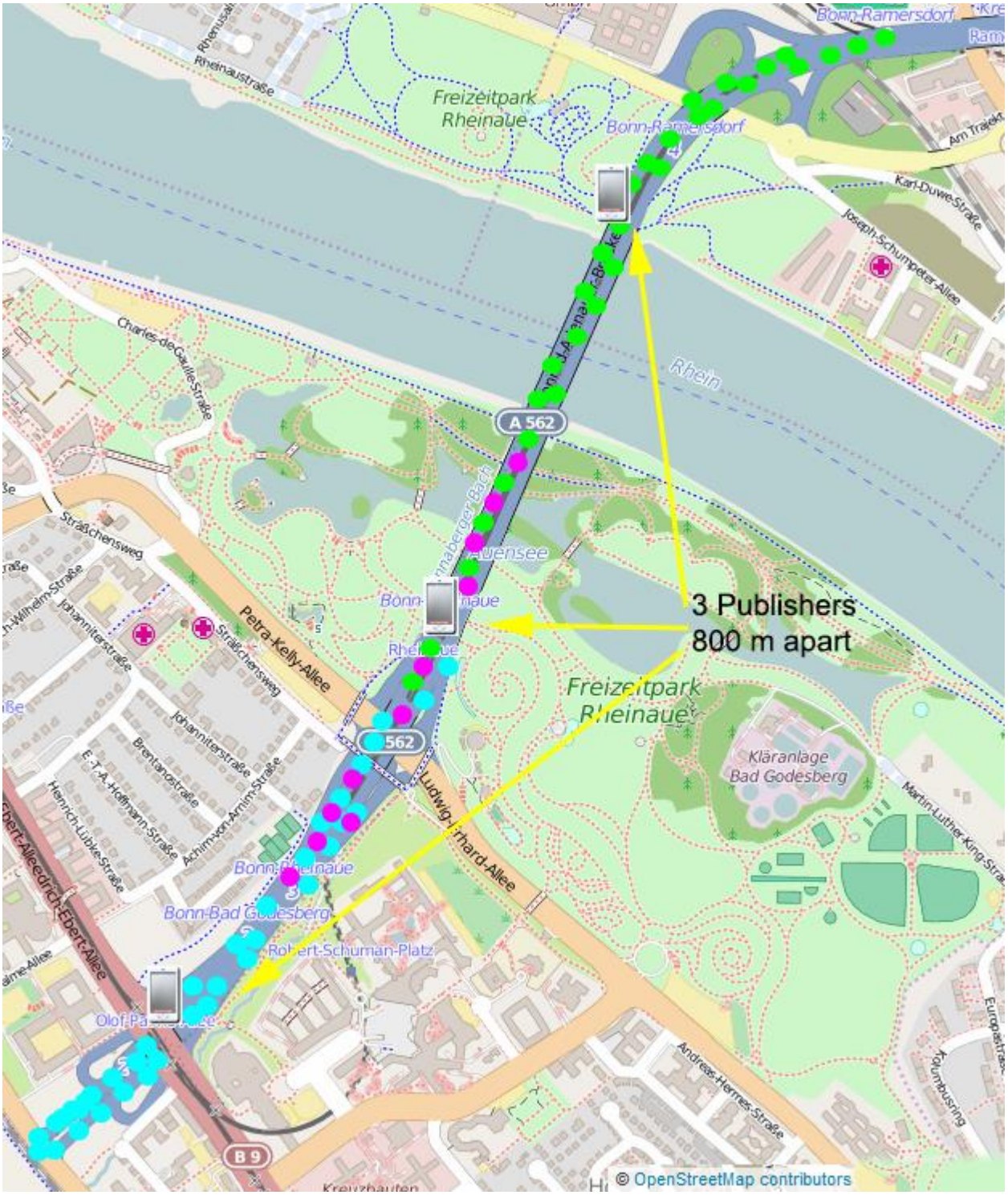
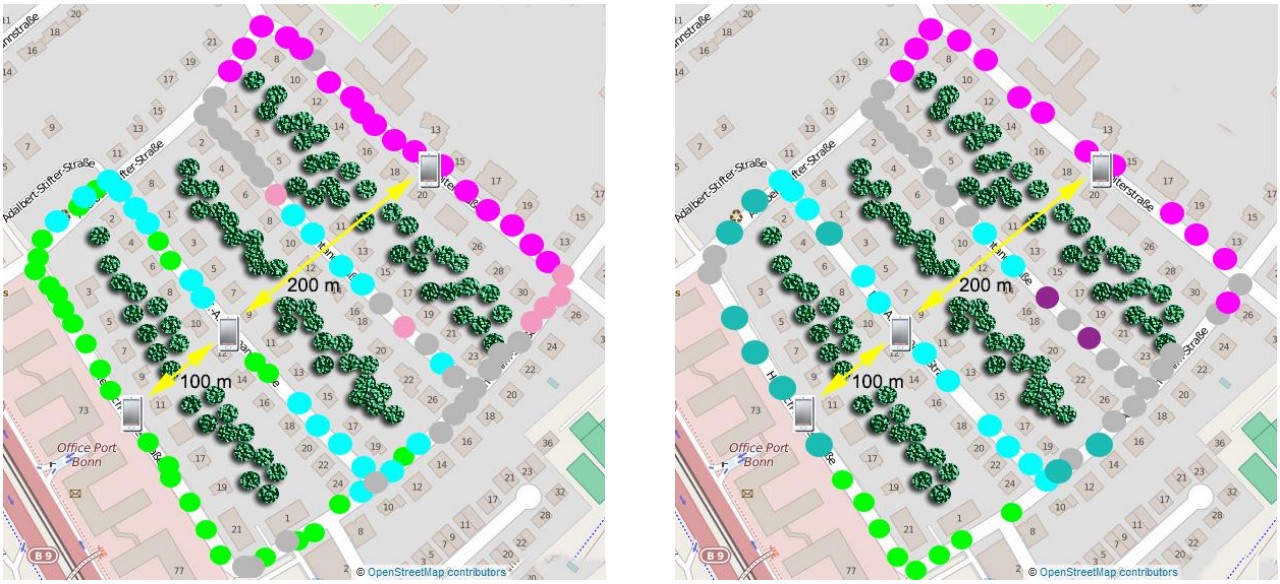


Figure 9: Mobility – Rural scenario

3.3.2 Urban scenario

The mobility test in the urban scenario was conducted with 3 publishers placed 100 and 200m apart as shown in Figure 10.

The tests were conducted with speeds of 30 km/h and 50 km/h. There was no impact on the discovery range as a result of mobility at these speeds. As with any NLOS test the discovery range is tied to the NLOS conditions. In practice, there needs to be a tradeoff between discovery intervals and high mobility discovery.



30 km/h **50 km/h**

Figure 10: Urban mobility scenario (30 km/h and 50 km/h)

3.4 Transmit power impact

The impact of varying the transmit power on the discovery range was evaluated on the Outdoor scenarios in Sections 3.1.1, 3.1.2, and 3.1.3 and on the indoor scenarios in Section 3.2.1, 3.2.2, and 3.2.3.

The different power settings for the tests were 23 dBm, 0 dBm, and -23 dBm.

The results from the outdoor and indoor tests are summarized in Figure 11 and Figure 12.

The discovery range varies significantly with transmit power and depends on the propagation environment. This allows the system to be tuned to various practical scenarios where range can be changed to suit the needs of the applications and use cases.

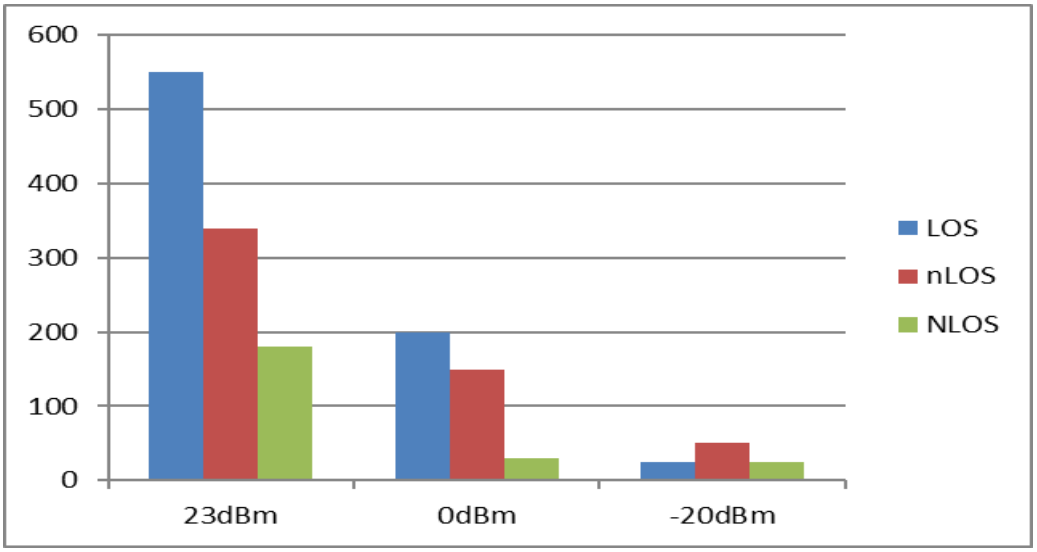


Figure 11: Varying transmit power – Outdoor scenario

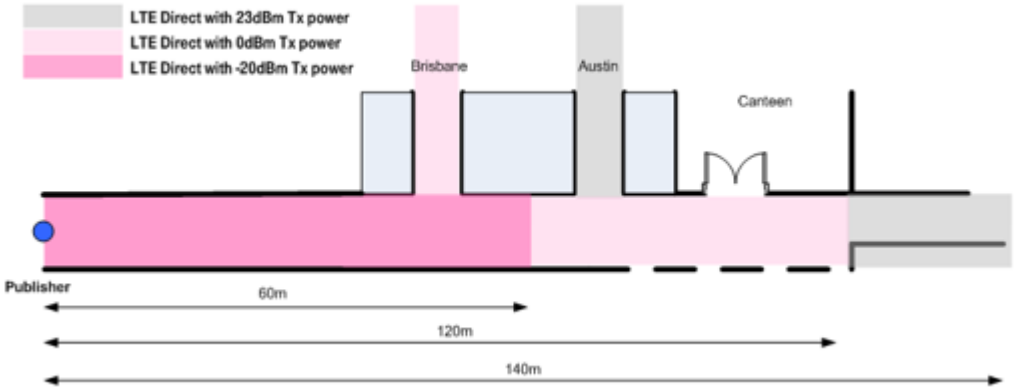


Figure 12: Varying transmit power – Indoor scenario

3.5 Interference test

The goal of this test was to investigate the impact of discovery on LTE traffic and vice versa. The subscriber UE and publisher UE were placed next to each other.

The test were conducted with both UEs transmitting full buffer UL and DL traffic, full buffer UL only, and both full buffer UL and DL traffic.

As seen from the following results, allocating subframes to LTE Direct discovery resulted in throughput loss proportional to the allocated resources for Discovery. This test affirmed the ability for LTE Traffic and Discovery to co-exist with minimal impact to the LTE network, creating a huge potential for new applications and services for LTE.

Table 2: UE LTE uplink and downlink throughput

Throughput	LTE Only (Mbps)	LTE + LTE D (mbps)
Uplink	3.845	3.64
Downlink	13.905	13.165

Table 3: UE LTE uplink throughput

Throughput	LTE Only (Mbps)	LTE + LTE D (mbps)
Uplink	3.905	3.745

Table 4: UE LTE downlink throughput

Throughput	LTE Only (Mbps)	LTE + LTE D (mbps)
Downlink	13.66	13.49

3.6 Wi-Fi Direct discovery range comparison

The Wi-Fi Direct discovery range at 2.4 GHz was tested in the Rural LOS, Urban LOS and Urban NLOS conditions as described in Sections 3.1.1, 3.1.2, and 3.1.3. Table 5 summarizes the performance of Wi-Fi Direct discovery as compared to LTE Direct. The difference arises from the 20 dB link budget benefit of LTE Direct discovery compared to Wi-Fi.

Table 5: Wi-Fi Direct vs LTE Direct discovery range

	Rural LOS	Urban LOS	Urban NLOS
Wi-Fi Direct (2.4 GHz)	200m	150m	30m
LTE Direct (2.6 GHz)	550m	350m	170m

Wi-Fi Aware is a recent proximate discovery feature of Wi-Fi. It has the same underlying physical layer and link budget as Wi-Fi Direct and will therefore exhibit the same Wi-Fi direct discovery range in the above scenarios.

4 Conclusions

LTE Direct is a 3GPP Release 12 feature that enables long-range, always-on, autonomous proximal discovery at scale, enabling continuous and passive lookout for relevant value in one's proximity. LTE Direct operates in licensed spectrum controlled by operators. This provides operators with an unprecedented opportunity to monetize proximity services developed on LTE Direct.

This paper presented the results of the LTE Direct trial performed by Deutsche Telekom with trial infrastructure provided by Huawei and prototype devices from Qualcomm. The trial validated the long discovery range of LTE Direct compared to Wi-Fi (550m vs 200m in Urban LOS Conditions). The consistent performance of LTE Direct in mobility conditions showed the robustness of the technology. The technology also demonstrated the flexibility to tune the discovery range by varying the transmit power. All of the above results show the great value LTE Direct can create for operators to enable proximity services with minimal impact to their network resources (<1% of one channel) and yet provide a plethora of use cases to increase the value of the LTE Direct beyond a data pipe.

This trial proved that operators could enable LTE Direct based proximity services to create tremendous value for their licensed spectrum assets with minimal impact on resource consumption.

Appendix A: Simulation Comparing LTE Direct with Wi-Fi Direct

This section presents the results of the simulations by Qualcomm comparing LTE Direct performance with Wi-Fi Direct.

The two metrics measured were the number of UEs discovered and the amount of time the devices needed to stay on to discover the devices. The results from the simulation are summarized in the following table[3] .

	LTE Direct	**Wi-Fi Direct**
Number of devices discovered	7200	369
Active duration(s)	0.64	82

LTE Direct discovers far more devices as result of a much better link budget compared to Wi-Fi. The FDM design of LTE Direct in which UE transmissions are packed efficiently in time also contributes to a much larger number of devices being discovered. This efficient packing also explains the much lower active duration. Wi-Fi Direct on time suffers as a result of message-based connection-oriented discovery.

[3] *Assumptions: Outdoor dense deployment scenario (e.g., Times Square); Ped A channel model, ITU-1411 pathloss model; Wi-Fi Direct – 10 dB shadowing and 20 dB wall penetration loss; BW − LTE Direct 10 MHz, Wi-Fi Direct – 20 MHz @ 5 GHz; 23 dBm Tx power, -5 dB antenna gain, 7 dB noise figure*

Appendix B: Simulation Comparing LTE Direct with BT-LE

This section presents the results of the simulations by Qualcomm comparing LTE Direct performance with BT-LE.

The following table summarizes results of the simulation:[4]

	LTE Direct	**BT-LE**
Discovery Density (# of devices covered)	Thousands	Hundreds
Range (m)	~500	~50
Active Duration (ms)	~75	~4000

The discovery range above was also observed over the air as part of the Deutsche Telekom LTE Direct Trial.

LTE Direct FDM design efficiently packs UEs while achieving high link budget resulting in discovery of far more devices and significantly lower power compared to BT-LE.

BT-LE on time suffers from asynchronous nature where a receiving device does not know when an announcing device is transmitting. This results in high scan duty cycle. The on time also suffers since BT-LE devices transmit and scan across three channels.

[4] *Assumptions: Outdoor deployment model (e.g., farmer's market), Ped A channel model, ITU-1411 pathloss model, carrier frequency of 2 GHz for LTE Direct/2.4 GHz for BT-LE, system bandwidth of 10 MHz FDD for LTE Direct/2 MHz for BT-LE, LTE Direct protocol implementation of 75 subframes every 18 sec, BT-LE beacon protocol implementation of advertising for 1.518 ms every 1.20 sec with <20% collision/scanning for 256 ms every 1.28 s.*