3GPP LTE-Assisted Wi-Fi-Direct: Trial Implementation of Live D2D Technology

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This paper is a first-hand summary on our comprehensive live trial of cellular-assisted device-to-device (D2D) communications currently being ratified by the standards community for next-generation mobile broadband networks. In our test implementation, we employ a full-featured 3GPP LTE network deployment and augment it with all necessary support to provide real-time D2D connectivity over emerging Wi-Fi-Direct (WFD) technology. As a result, our LTE-assisted WFD D2D system enjoys the required flexibility while meeting the existing standards in every feasible detail. Further, this paper provides an account on the extensive measurement campaign conducted with our implementation. The resulting real-world measurements from this campaign quantify the numerical effects of D2D functionality on the resultant system performance. Consequently, they shed light on the general applicability of LTE-assisted WFD solutions and associated operational ranges.

Keywords: 3GPP LTE, cellular assistance, commercial opportunities, device-to-device, live trial, performance measurements, standardization, Wi-Fi-Direct.

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I. Introduction

Device-to-device (D2D) communications technology as part of the 3rd Generation Partnership Project (3GPP) Long-Term Evolution (LTE) Release 12 specification [1] enables novel unprecedented opportunities for next-generation peer-to-peer (P2P) and location-based applications and services [2]. Most of these new opportunities emerge from discovering and exploiting user proximity, which is provided by virtue of location services in contemporary mobile broadband networks [3]. Together with improvements in network capacity, data delivery latency, individual user throughput, and energy efficiency, D2D also brings along attractive new business cases for network and service providers.

With our preliminary research [4]–[5], we have identified numerous benefits that could become available if a coordinated, network-assisted D2D technology is deployed by network operators. On the other hand, introducing D2D technology within today's network infrastructure poses a number of challenges and requires updates to the current longstanding cellular architecture. Therefore, to conduct a comprehensive study and reveal the practical promises of D2D communications, we have designed a trial development and deployment program. Our trial was aimed at demonstrating how the direct connectivity paradigm could be seamlessly integrated into a real-world, operator-grade cellular network with minimal modifications and overheads, as well as within a reasonable time frame. Our secondary goal was to quantify gains that could be achieved by a fully-functional, operator-supported D2D system. To complete these challenging objectives, we have defined a deployment time constraint of one month and assigned a team of six qualified engineers for

Fig. 1. Part of experimental LTE network at BUT, Czech Republic.

the said implementation.

As a basis for our trial, we have utilized the experimental LTE network of Brno University of Technology (BUT), Czech Republic, which supports most of the functionality expected of LTE Release 10 systems (see Fig. 1). During the trial, we upgraded the LTE network of BUT with our own implementation of Proximity Services (ProSe) functionality as envisioned by the 3GPP specifications [6]–[7]. This has allowed us to perform live D2D integration trials, along with corresponding performance evaluations, and we systematically report all of our most important findings in this paper.

The rest of this paper is organized as follows. In Section II, a review of the D2D-enabling standards and technologies is conducted. Further, we outline the envisioned D2D system design and operation in Section III. Section IV, in turn, elaborates on the resultant practical implications of our vision. Finally, in Section V, we discuss our performance evaluation summary of the developed D2D system together with some insights into the realistic aspects of D2D operation and usage.

II. Overview of Technologies and Standards Enabling D2D Communications

The range of applications for D2D connectivity in cellular networks is truly wide [8]. Prospective D2D use cases vary from local voice and data services (offloading calls between proximate users) to context-aware applications, augmented reality, and public safety.

1. Current D2D Technology Candidates

Presently, the most widely adopted technology candidates for direct connectivity are Bluetooth and Wi-Fi, which operate in the 2.4 GHz unlicensed spectrum. Other popular wireless networks, such as those proposed by IrDA and ZigBee alliances, are not targeted for generic D2D communications [8] by their design. As a result, Bluetooth is mostly used today for personal area networking, whereas Wi-Fi remains popular whenever high-rate user device connectivity is required. However, employing conventional Wi-Fi and Bluetooth for D2D communications is rather cumbersome and does not guarantee any quality of service (QoS) levels. Addressing the usability problems to some extent, a Wi-Fi-Direct (WFD) protocol [9] has recently been introduced. WFD enables direct communication possibilities without the need for Wi-Fi infrastructure, and does so with minimal user interaction; thus, this essentially allows a device to act as a network controller (a.k.a. "group owner"). WFD also provides a way to set up multiple networks at the same time, thus enabling multiple devices to communicate IP data directly between each other [10].

2. Network-Assisted D2D Communications

Since market penetration of WFD is already high and is only expected to grow further, this technology becomes increasingly attractive for envisioned cellular-assisted D2D communications. It is evident that for future D2D systems to benefit consistently from WFD, it is necessary to minimize the signaling overheads of neighbor discovery [8], [10]. This signaling load can be reduced with the help of an authoritative entity (for example, a mobile network operator), where several key functions of D2D connectivity would be managed by the cellular network infrastructure [4].

Consequently, current mobile broadband networks may provide proximal devices with efficient mechanisms to establish and maintain a D2D connection. This is required, first of all, to enable at least some form of fallback, which is a crucial consideration for reliable proximity-based applications. However, by utilizing the centralized control function and, in particular, user location and signal level monitoring mechanisms of LTE networks, it is also possible to coordinate a D2D network, improving the overall system efficiency.

In contrast to the "loosely-controlled" D2D mode discussed above, a fully-controlled D2D operation in licensed cellular bands is currently anticipated with the advent of LTE-Direct [11], which represents a system under the control of a cellular

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network operator. LTE-Direct is presently under heavy development, but the real-world deployments of this technology are not expected earlier than in several years from now due to many associated technical and market challenges [11].

As expected, there are several major complications in running D2D over licensed bands, such as cumbersome interference management (which is attractively simplified in WFD), additional transceiver design and standardization efforts (in WFD, stock Wi-Fi transceivers are used), and multiple other issues. Therefore, the main focus today remains on D2D communications over unlicensed bands, which is primarily achieved with LTE-assisted WFD.

3. D2D Standardization Activities

The key enabling technologies for D2D communications have been around for years, since practically any IP-ready mobile device is tentatively capable of direct connectivity. However, the development of the necessary supporting standards and user interfaces has woefully lagged behind any developments in related technologies, with the first D2D activity started by 3GPP in 2012 within the framework of ProSe. 3GPP TR 22.803 [6] is known as the initial document to specify what exactly is to be understood by the term "proximity-based services," and D2D naturally fits into this category. However, 3GPP ProSe specifications and associated work items cover, in fact, a much broader area. They address the phenomena in both society and economy that drive the need for proximity-based communications, including such examples as social networking; disaster relief and emergency service operations; advertising; and so on [8], [12]. As a result of this work, the decision was made that ProSe functionality was to become a part of future LTE releases.

Consequently, the technical side of providing ProSe mechanisms demanded attention. In particular, a requirement has emerged on establishing proximity in an efficient way without revealing personal user information. Indeed, proactively requesting any content via short-range radio links discloses the type of the desired content, whereas broadcasting content advertisements discloses what is available to share. Either way, users of a proximity-based discovery service, both content providers and consumers, may prefer to remain anonymous or impose their customized policies on a set of targeted peers. With decentralized solutions, such as those offered by WFD, meeting the above requirements is clearly impossible. This, in turn, has led to research on a potential Evolved Packet Core (EPC)-level discovery procedure, where a 3GPP network would act as a trusted intermediary and implement all of the necessary policies on behalf of users. The report TR 33.833 [13] quantifies specific goals, which have been respectively targeted by 3GPP.

Currently, since the overall vision of how the ProSe function is to be implemented has already taken shape, follow-up work has begun on support infrastructure, such as billing [14]. As of 2015, most of the architectural progress on ProSe and D2D communications is summarized in the TS 23.303 document [15]. It is likely, however, that additional amendments will be made when activities on the technical side of LTE unlicensed [16] commence. Today, some of the related ideas on potential license-assisted communication (RP-140770) and on LTE-based short-range radio within licensed bands [17] have already been documented.

However, aside from their in-house efforts on short-range radio, 3GPP also supports alternative non-3GPP radio technologies, including WFD, for ProSe radio communication. The integration between 3GPP and Wi-Fi solutions has been a long-standing effort, with specifications TS 23.234 [18], TS 23.327 [19], and TS 23.402 [20] outlining how LTE devices that are connected over non-3GPP access technology could still receive access to all of the 3GPP services. Following this lengthy integration effort, all current ProSe architectures support the use of IEEE 802.11 family, as a link layer for most of the ProSe functions, with the exception of public safety services [15].

In our trial implementation, we have been relying on 3GPP specifications as much as possible within the limitations of the target deployment. In the following section, we describe in detail what exactly has been developed and what obstacles have been encountered.

III. LTE-Assisted WFD D2D System Implementation

1. D2D Trial: Architectural Considerations

Our envisioned implementation of the generic D2D system concept offered by the standards has naturally met a number of deployment challenges that made us deviate from the reference solutions. Current architectural considerations of LTE networks preclude us from deploying the network assistance functions in the way that would have been the most "natural" from an engineering standpoint; thus, we had to adopt several clever workarounds to develop a workable system with today's technology. In what follows, we review the key decisions made in each step of the deployment process and explain our motivation behind them.

The experimental cellular network setup installed at the Department of Telecommunications, BUT (see Fig. 2) is a complete commercial-grade implementation of all the crucial subsystems comprising contemporary 4G mobile networks.

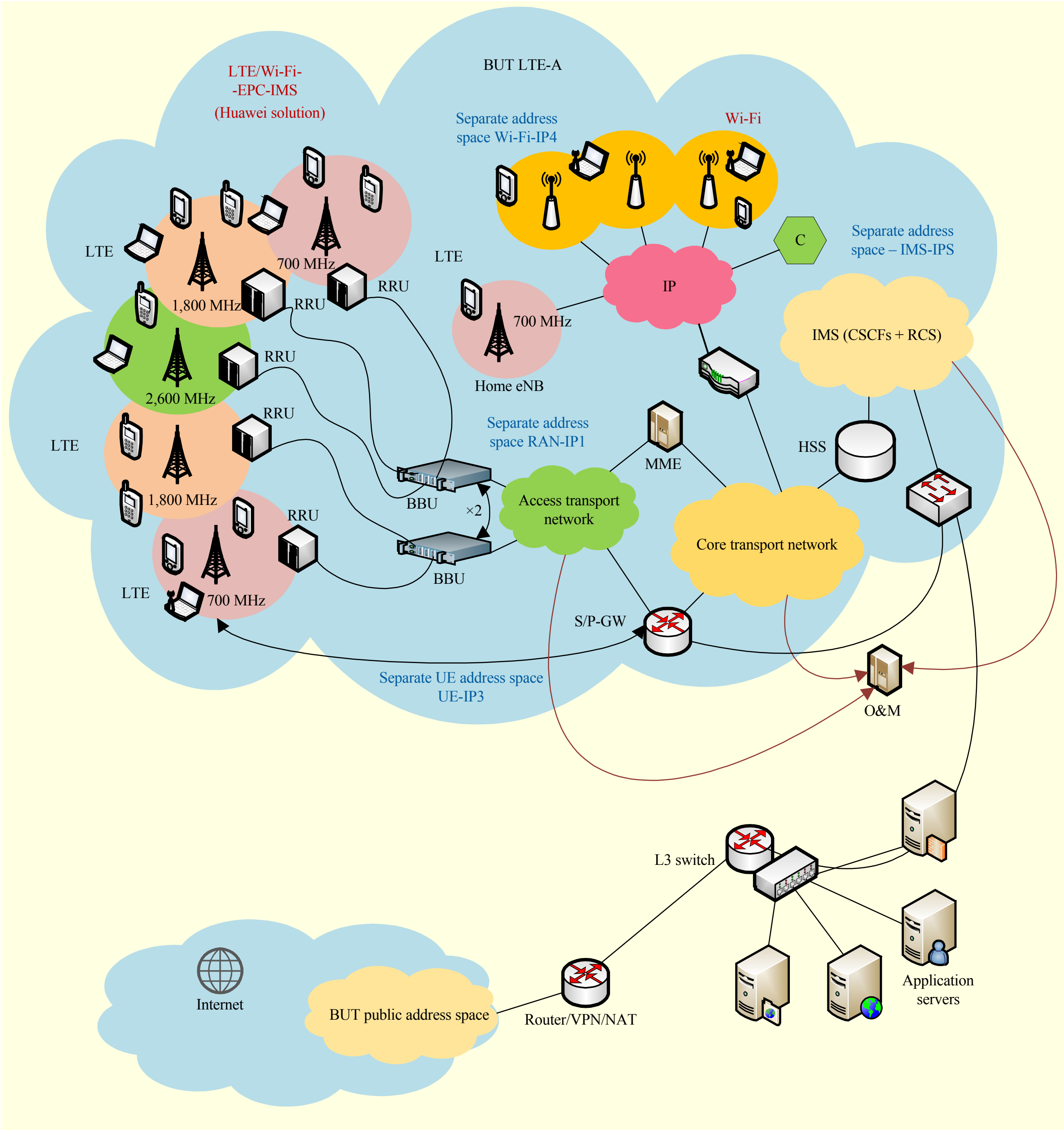

Fig. 2. System topology of experimental 4G cellular network deployed at BUT.

Our trial deployment is configured to provide the necessary packet-switched data access services and their derivatives, such as VoIP communications over converged LTE and Wi-Fi radio access infrastructure. The EPC is dimensioned to enable high data rate services with appropriate QoS provisions, as well as to support up to 100,000 concurrently served users. For voice and video calls, the switching capabilities are implemented by employing the high capacity IP Multimedia Subsystem and its related components, for both mobile and fixed access users, as well as for connectivity to external telephone networks and teleconferencing systems.

The general goal behind BUT's LTE test network deployment has been achieving the synergy of a complete and customizable experimental mobile network that allows for rapid implementation and prototyping of novel concepts and technologies, such as the D2D communications paradigm discussed at length in this paper. We thus effectively used this asset to showcase that the LTE-assisted WFD technology has matured enough for an example implementation in a commercial-grade LTE/Wi-Fi network.

However, several LTE mechanisms expected by the ultimate network-assisted D2D architecture were not available at the time of our early implementation. This included the evolved Serving Mobile Location Centre (e-SMLC) server, for which an alternative interface to obtain device location information directly from a Mobile Management Entity (MME) has been developed as a substitute. In addition, the D2D server functionality has been implemented as a virtualized appliance, whereas the final commercial operator-grade implementation should preferably use a more robust technology. Further design choices are explained below.

2. Impact of Radio Access Network on D2D Communications

A radio access network (RAN) is crucial for any kind of service in a mobile network. To this end, RAN is typically required to transport signaling and data. That being said, D2D communications are not particularly demanding with respect to RAN capacity, as D2D messages are only a few bytes in size, and ultimately D2D communications reduces the RAN load. The D2D signaling should, however, be prioritized to decrease service response times. Correspondingly, the impact of RAN loading on the observed service times has been measured extensively in our experiments (see Section IV).

Other RAN functionality required for LTE-assisted D2D communications is positioning. Providing user location information is achieved via cooperation between eNodeBs and other EPC elements, and is described at length in Section III-6. Notably, neither special configuration nor non-standard service is needed from the RAN side for the D2D system to function.

A deployed RAN is part of our test-bed installation. Generally, commercial-grade equipment is used, but the RAN itself is not a part of the radio access subsystem of a mobile network operator. Hence, we have complete control over the RAN loading conditions. Finally, as our RAN solution is deployed in the real world, external interference is present.

3. Providing Unrestricted IP Connectivity

One of the key requirements for any direct user connectivity is the ability to communicate between devices without any intermediary hosts operating at the transport layer or above. Typically, in cellular networks, the associated devices acquire their IP addresses from private ranges (for example, 192.168.0.0/16). As long as a D2D link is set up within a single operator's network, this does not impose any constraints. However, the effective firewall policies deployed in the core network, which deny direct access between user devices to enhance security, actually cause difficulties. The original purpose of the aforementioned firewall policies could have been prevention of undesired incoming connections and P2P data transfer between different mobile network users. As a result, they deny any and all P2P connectivity over cellular networks [21].

For the purposes of our network-assisted D2D trial, we needed to circumvent the firewall by making the D2D server open direct communication paths for selected connections whenever necessary. In our case, implementing such functionality has been fairly straightforward, since the D2D server can reconfigure the firewall on a per-connection basis. In our implementation, the firewall is located inside the Unified Gateway (UGW) entity; logically composed of a Serving Gateway (SGW) and Packet Data Network Gateway.

4. Communication between D2D Server and Users

By design, D2D network assistance relies on a network's ability to communicate with those user devices that are engaged in direct connectivity with the network. This inherent ability must be augmented by an efficient means of initiating such communications. For example, the said connectivity could be straightforwardly enabled with a session initiation protocol, but this would require an active radio bearer. Having an active LTE radio bearer for only several packets is naturally

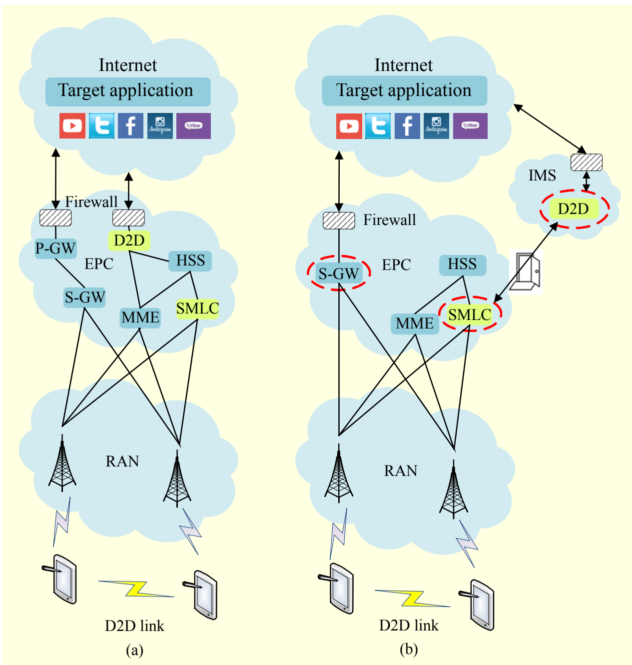

Fig. 3. Comparison between (a) hypothetical/standardized and (b) our deployed implementations of D2D system in 4G mobile networks.

not conducive to system efficiency; hence, this is to be avoided. In LTE, there are multiple ways to transfer short messages between a network and those individual users of the network that do not require a dedicated bearer setup, such as non-access stratum (NAS) signaling, which is typically used to set up the bearers themselves.

As a result, the practical deployment of the D2D functionality requires an implementation where the D2D server would be positioned outside of the system core as a conventional IP service, but with a capability to access certain core network functions (see Fig. 3). While this may not be the optimal solution in final commercial deployments, it enabled us to move forward promptly with regard to D2D system implementation. Although the proposed location of the D2D server does not follow the 3GPP guidelines exactly, we believe that our modification does not produce any negative impact with respect to latency, as the connection between the SMLC and the D2D server is implemented via a tunnel over a fiber channel.

5. Integrating Location Services

For the network-assisted direct connectivity to operate efficiently, the D2D server needs regular updates on the current locations of users. In LTE, such information is conventionally aggregated by the e-SMLC entity to be then made available for the user devices via Secure User Plane Location (SUPL) bearers. A copy of the location information in question is typically stored inside the MME for its internal usage.

Whereas the exact means of how this information is obtained may vary, the general procedure is such that a phone's GPS location will be used if available. Alternatively, the positioning reference symbols within the LTE frame will be used to pinpoint the location of user equipment (UE) through triangulation. Either way, the coordinates are obtained in line with the standard techniques outlined by 3GPP and are enabled in most modern equipment (post Release 9). As a result, enabling location-based services is not a major challenge in contemporary LTE networks, and most of the time such functionality is already provided by the operators for the mobile devices to use.

In the considered proximal scenario, the D2D server accesses the location information on behalf of the UE, and then draws conclusions on whether other UEs are sufficiently close to initiate direct communication. An example of such decision logic is presented in Fig. 4. With the help from location services, the UE can thus power on its radio only when the intended contact is in proximity, hence saving battery and network resources. The specific signaling used in the trial is further discussed in Section IV. Naturally, one would need to

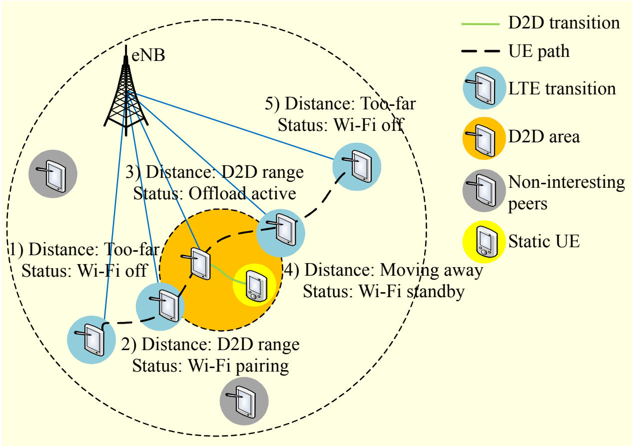

Fig. 4. Switching logic between LTE and proximal D2D connections, as mobile UE is moving along its route and meeting static D2D peer.

select the thresholds triggering various decisions, but those are largely hardware-specific and have not been the core subject of this study.

6. Linking D2D Server and Core Network Components

Recall that the location information is typically made available in LTE only for MME and the UEs themselves. Similarly, the interfaces to control the firewall policies at the UGW are also core-local. In our implementation, we had to create a secure connection to the core to allow the D2D server to communicate with the MME and UGW, as to extract the location information and configure firewall policies via the maintenance interfaces, which is, of course, not the preferred final solution to go with.

In reality, one would require enabling the D2D server to connect to the MME/SMLC and UGW via an efficient and secure application programming interface (API), without exposing the entire management console. Due to the time limitations imposed by the purposes of this trial and to the vendor-specific nature of the firmware, we have left the development of such API for future work.

7. D2D Connection Control

Efficient control of D2D connectivity between UEs deserves a separate dedicated research, which can be generally split into signaling and executive components. The signaling may be handled by a service that is running as a service on the mobile device, whereas the executive part is essentially integrated into the kernel drivers of the operating system (OS) of the UE.

While implementation of the signaling part as an application is rather trivial for most of today's mobile phones, actually forcing control over Wi-Fi and cellular connections (together with the associated routing table) requires significant modifications to the permission levels of the UE. In practice, for most platforms (Android, the majority of Linux-based systems, and so on), this means employing custom-built firmware for the phone, or obtaining the administrative privileges by virtue of hacks and exploits. For closed platforms, such as iOS and Windows Phone, these solutions are nearly impossible without cooperation from the platform vendors.

IV. Performance Evaluation of Implemented D2D System

The primary goals of our performance evaluation are as follows:

- Indicating bottlenecks that could potentially hinder the adoption of D2D connectivity in future wireless technologies.
- Establishing appropriate performance bounds and limitations for D2D technology, as well as outlining what services could be most suited for direct communications in contemporary and near-future markets.

To achieve these diverse goals, we follow the measurement procedures as outlined in the remainder of this section.

1. Measurement Methodology

It is important to note that in this work (by contrast to numerous past publications) we are not interested in the performance of the D2D link itself, since that would largely depend on the current channel and user contention levels. In this study, we only concentrate on assessing signaling performance and network assistance logic, as the latter can be reliably measured in our controlled trial environment. On the other hand, such metrics as D2D throughput are extremely difficult to assess conclusively in practice due to the high variability in wireless environments.

Based on the above reasoning, the single most important parameter of D2D signaling is the connection setup time. This latency is crucial, as lengthy connection setup times may delay the transfer of the flow to an alternative radio link, thus affecting other parameters such as energy efficiency and user experience.

Due to small message sizes, in the order of a few tens of bytes, other QoS requirements on the D2D signaling are trivial and can be provided by any access network; therefore, we are not considering these as key performance indicators for this technology. Other aspects of D2D link performance, which are not directly related to mobile network infrastructure, do not affect service setup response times and, as such, are out of the scope of this work. The connection setup time may in turn be decomposed into several components, as described below.

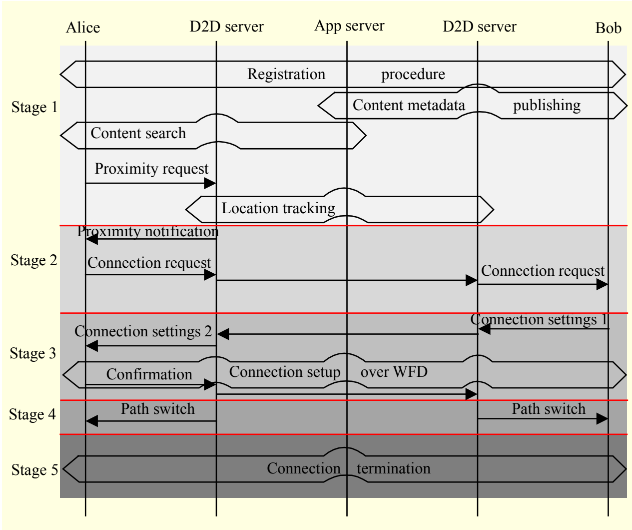

Fig. 5. Considered D2D protocol signaling including all five stages required for proximity discovery, D2D link establishment, and termination.

First, by looking at the proposed D2D protocol signaling illustrated in Fig. 5, we learn that before any WFD connection is actually set up, there are several important actions to be taken from the network side to establish user proximity. Therefore, we would like to decompose the signaling procedure in question into several distinct stages. In stage 1, the responsiveness of the system is not of particular interest, since the procedures taking effect there are constrained primarily by the human user input.

However, once stage 1 is completed and the proximity is established, the actual D2D signaling is triggered. Ultimately, we would like for stages 2 (D2D link negotiation), 3 (link setup), and 4 (actual flow switching) to occur as quickly as possible to maximize the effective time during which we can take advantage of the D2D link, especially if the communicating peers are highly mobile. These stages also constitute natural measurement checkpoints, where the resultant system agility would straightforwardly depend on how long it takes to transit from one checkpoint to another. Therefore, we further commit to measure an aggregate latency at each of the above state transitions.

To provide the best available accuracy, we have additionally decomposed the considered D2D protocol into individual messages and performed our measurements on a statistically large sample set. The latency has been measured between the client device (laptop Lenovo T430 with the USB LTE modem Huawei E392) and the D2D server (located behind the UGW). Utilizing the modem E392, the laptop has been connected to our experimental BUT LTE network. The distance between the client and the eNodeB has been fixed to 5 meters throughout the entire performance evaluation campaign. As a measurement tool, Iperf [22] has been employed to assess the maximum throughput of a particular radio access solution. Later, Iperf has also been used to create predefined loading on both uplink and downlink channels to thus emulate specific conditions on a "deployed" network. The client has been configured in the role of a sink (receiving data traffic from the D2D server) and a generator (generating the constant User Datagram Protocol (UDP) data bit stream for Iperf, which runs on the D2D server).

The WFD D2D link setup times have been measured between two Sony Xperia ZL phones, running custom Cyanogenmod 10.2 aftermarket firmware. The link setup time has been assessed following the known-channel preshared key (PSK) authentication procedure (essentially, employing the Wi-Fi Protected Access II (WPA2) protocol).

The WPA2 authentication enables legacy devices (which do not support WFD extensions) to still join the networks initiated by other devices. The measurement for the connection setup time has been done with the wpa_cli interface, by monitoring the time between when a new network has been enabled and when a new connection has been completed. A connection was considered completed once the first IP packet was successfully acknowledged.

2. Numerical Results and Discussion

Following the above methodology, the measured values of the LTE network latency have been obtained to compose Table 1, which summarizes the estimated delays introduced by various connection setup stages. Here, the stage 3 delay includes Wi-Fi link setup, as discussed further on. The fractional loads on Wi-Fi and LTE networks have been matched (that is, 10% load on Wi-Fi is used when 10% load is on LTE). For LTE, our results indicate that if the overall loading on the LTE network does not exceed 90%, the round-trip times (RTTs) between the client and the D2D server are generally below 30 ms. Hence, cell loads of up to 90% do not have any evident effect on the D2D signaling procedure when compared with the Wi-Fi link setup time. Under higher loads, the Wi-Fi setup time becomes comparable with the LTE latencies, thus making LTE signaling optimization a concern. This is especially critical since offloading is most needed under high loads.

In the case of 99% load, the network queues have been overfilled; we can assume this particular scenario to be highly relevant for an offloading operation. The resulting LTE RTT values range in the order of half a second, and without the appropriate QoS support in LTE the obtained latency values would dramatically impact the overall performance of the considered D2D technology.

Further, Fig. 6 clarifies the delay values for the different types of cell load. Whereas the values remain negligible for up to 90% loading, the "full-buffer" condition yields a major increase in the monitored delay, which becomes hardly acceptable (in the range of seconds). Therefore, we paid close attention to the measurements in the range 91% to 99% of cell loading. In this extreme case, the implementation of QoS on the UE side is crucial to prioritize the D2D signaling messages, see Fig. 7.

It is evident that the network conditions remain reasonably stable for up to an extremely loaded state (corresponding to a cell load of 99%). Under extreme loads, the average latencies remain largely acceptable; however, due to the high variance,

Table 1. Network latency measurements for different cell loads.

Cell and Wi-Fi load	Idle (10%)	50%	90%	99%
Measured RTT (ms)	18	25	27	60
Stage 2 (ms)	36	50	54	120
Stage 3 (ms)	750 + 36	850 + 50	1,000 + 54	1,150 + 120
Stage 4 (ms)	9	13	13	30
Full procedure (ms)	849	988	1,148	1,480

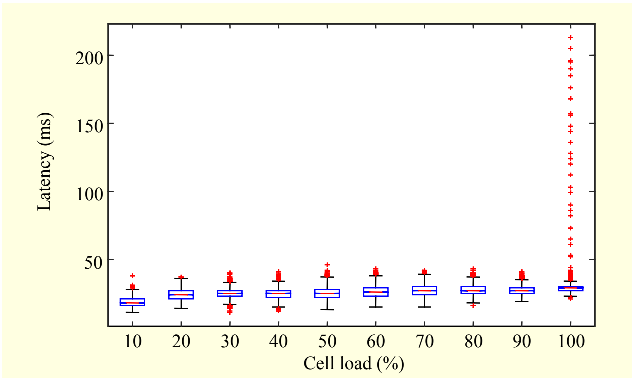

Fig. 6. Network latency for alternative LTE cell loads.

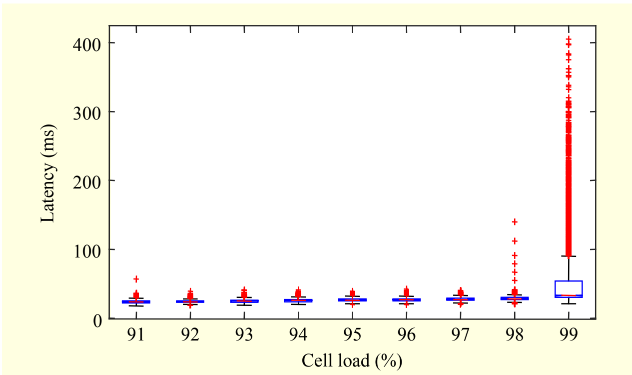

Fig. 7. Network latency for extreme LTE cell loads.

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the perceived quality of user experience suffers significantly.

Interestingly, out of all the D2D connection stages, by far the most costly ones are connection negotiation and the actual setup of the link. In practice, those require several RTTs to complete and may add up to several seconds of signaling time in highly congested cells. Naturally, this necessitates further improvements to how the signaling messages are carried, since the primary goal of D2D is to actually reduce the load on the cellular links; moreover, the longer it takes to perform D2D offloading, the worse the resultant congestion levels will be.

It is noteworthy that the D2D-link teardown procedure at stage 5 is not instant. However, since the direct links are removed only when they are not needed anymore, this teardown procedure is not as time-critical. Hence, it is not evaluated explicitly by our present study.

3. Performance Summary

Based on the performance numbers obtained above, one can conclude the following on the current bottlenecks of the LTE-assisted WFD implementation:

- The WFD link setup time could be dramatically shortened by removing the OS-introduced delays. While this does not significantly affect user experience, it does delay the actual start of offloading. Under most conditions, this overhead is nearly constant.
- The D2D connection negotiation stage is the primary bottleneck in an idle LTE system, as it involves multiple RTT cycles to complete, and can grow exceptionally under heavy cell load.
- In a loaded network, any communication with the D2D server may take a considerable amount of time since the signaling traffic shares the same channel with the data traffic due to the absence of dedicated bearer support in the mobile OS API.
- If the users are highly mobile, then their location tracking may become inaccurate, thus resulting in false proximity notifications or late link establishments due to relatively short durations of effective proximity.

We reiterate the fact that while the conventional performance metrics typically focus on throughput, in this particular case of offloading, the subject of specific interest is signaling procedure, rather than the gains ultimately attainable by its use. In the future, we hope to deliver a broader set of measurements to cover the throughput evaluation as well.

In summary, as far as future proximity-based services are concerned, we are convinced that it is entirely feasible to utilize our considered network-assisted D2D logic for mobile devices moving at least at pedestrian speeds. Whereas there is some additional delay introduced by network assistance signaling, in almost all cases the connection will be established on time for the users to reliably benefit from it before they come into physical contact, even when walking toward each other.

V. Conclusion

As the paradigm of proximal communications enters the mainstream of our society, we expect that telecommunication operators would be increasingly willing to provide D2D discovery functionality and associated automated services. Technology-wise, those services would most likely be shaped along the lines that we have identified in this article. Naturally, radio access technologies other than Wi-Fi may become adopted in the future, yet for the next several years we anticipate to see WFD–based solutions dominating the D2D scene. Whereas LTE-assisted WFD technology may indeed lack some of the efficiency promised by LTE-Direct and other cellular-only technologies, its ubiquitous availability in today's mobile devices is likely to remain unrivalled for at least a number of years to come.

However, despite all the research around it, the mobile network operators of today are not massively concentrating on business cases for assisted D2D communications. As a result, the supporting infrastructure for D2D connectivity in the current mobile platforms is significantly lacking, and it becomes up to highly specialized communities (such as academia) to provide model D2D solutions. To complement our proposed technical implementation of a network-assisted D2D system, we additionally elaborate on several potential business cases for such D2D connectivity.

We believe that D2D technology can be widely used for augmented reality glasses (given that the battery issues are resolved), social services for multiplayer gaming, dating, and other similar tasks, or context-based advertisements. Indeed, today, there are many companies that may wish to advertise their new products and services based on the location information of users. Further, the majority of social networks are already utilizing proximity-based services, with examples given by Foursquare, Twitter, and Trip Advisor.

Naturally, all of these business cases are already enabled presently with existing technologies. However, their somewhat counter-intuitive design makes the provision of privacy-oriented and reliable services an overly complex task. With the assistance coming from the D2D server, one can always find better answers to the major questions of proximal communications.

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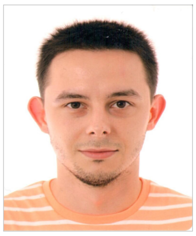

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