Underlay Loosely Coupled Model based on D2D Direct Communication for Public Safety Networks

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***Abstract*— In several emergency situations, during natural or human-caused disasters, frontline responders need communication and collaboration infrastructure to properly carry out the relief mission. Some countries are building their national Public Safety Mobile Broadband based on cellular LTE technology to provide fast, safe, and secure emergency services. Otherwise, in several emergency situations, the cellular antennas can be overloaded or partially damaged in manner to affect the group communication services. Since few last years, direct device-to-device (D2D) communications have been proposed by 3GPP as an underlay to Long Term Evolution (LTE) networks based on proximity, reuse, and hop gains. This paper focuses on the loosely coupled model based on D2D direct communication for Public Safety context. Many scenarios related to user membership and network management are detailed. Both "less cost" and "optimized tree" approaches are proposed, implemented, and their performance evaluated in terms of network updates number and resulting average Channel Quality Indicator (CQI). Other optimization approaches, with different CQI threshold and optimization interval parameters, have been simulated to compare their performance with the "optimized tree" approach.**

Keywords—Public Safety Network, D2D, Proximity Service, underlay networks, loosely coupled model, network simulation.

I. BACKGROUND AND MOTIVATIONS

Natural or man-made disasters like earthquakes, avalanches, floods, tsunamis, fire, massive pile-up or building collapse are occurring frequently in many places around the world. The need for communication services become very high during and after such events. In many cases, disaster scenario requires from rescue crew (firefighters, paramedics, police officers, etc.) to remotely interact with witnesses as well as with disaster survivors to coordinate together the rescue mission. In several emergency situations, the cellular antennas can be overloaded or partially damaged in a manner to prevent rescue teams from communicating.

The most famous Land Mobile Radio (LMR) technology have been extensively deployed in public safety contexts till now [1]. With data rates around several hundreds of Kbps, LMR networks show limitations when it comes to supporting bandwidth-intensive applications. Moreover, the LMR networks assigns a separated frequency range for each type of response team. Therefore, attention is drawn to the use of cellular long-term evolution (LTE) technology and beyond as access network support for public safety. Such solution is known as Public Safety Mobile Broadband (PSMB) like the *FirstNet* in the United States, *Emergency Service Network* (ESN) in the United Kingdom, or *SafeNet* in South Korea [2]. The operating principle of PSMB is to allocate a wide and low-frequency band (in the 700 MHz) which will be reserved exclusively for emergency situations. Unfortunately, the proposed frequency band can be saturated, or the disaster area might not be covered by the 4G/5G networks. Proposed solutions based on land/air vehicles to extend or reinforce cellular network are not usually obvious to deploy since heavy planning tasks are required and a considerable availability of qualified human resources is necessary to drive or command the engines. All these requirements make the deployment of PSMB solution extremely expensive, especially in countries with large territories and limited resources. On the other hand, for a few years, the Third Generation Partnership Project (3GPP) introduced Device to Device (D2D) technology [3], that enables direct connection where data plane can be handled by User Equipments (UEs) without crossing the cellular network infrastructure. This D2D technology can be coupled with the Proximity Service (ProSe) [4] that provides many functions including discovery, communication, and relay mode. ProSe technology allows UEs in proximity to discover themselves and to establish direct communication channels as soon as cellular operators enable the public safety mode. Moreover, out-of-coverage UE can use another UE as a relay to join the network. Compared to the proposed PSMB solutions, the deployment of D2D in public safety context offers mainly several benefits:

- Proximity profit with higher throughput, lower delays, and lower power consumption.
- Avoid overloading the central cellular antenna by dispatching media streams directly between participants.
- Extend cell range by using in-band D2D relay function to connect out-of-range devices.

This paper explores underlay networks models based on D2D by focusing on the loosely coupled topology. User membership and network management are studied, and some simulations are conducted to analyze the effects of user density and group connectivity as well as assessing optimization effect in terms of resulted average channel quality and number of links updates. The remaining of this paper is organized as follows: Section II provide survey of some existing solution for public safety context, section III present an overview of the underlay D2D network based on ProSe service, while section IV focuses on the loosely coupled model, section V define simulation environment and parameters while section VI show simulation results and performance analysis followed by concluding remarks.

II. RELATED WORKS

To minimize the impact of possible cellular network overload, or coverage limitation, the research community and

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the industry have recently considered the deployment of Unmanned Aerial Vehicles (UAVs) during the rescue mission. The UAV can play a fundamental role in supporting new value-added services and applications. Among these, we can mention remote sensing in surveillance operations [5], collaborative search and rescue [6], [7], building aerial sensor networks that aid disaster management [8], or supporting backbone communications to mobile ground stations [9].

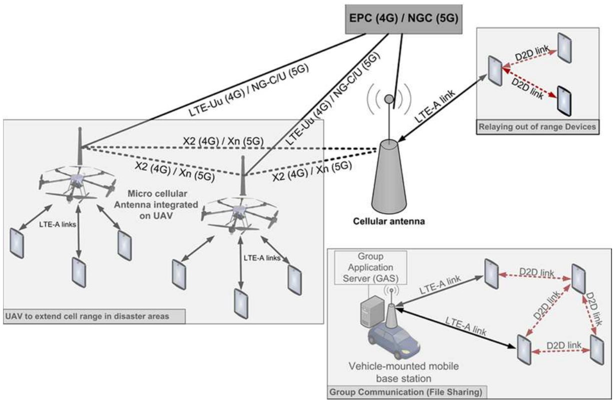

Fig. 1. Overview of some solutions for extending cellular coverage.

Instead of using UAVS, author in [10] propose the deployment of vehicle-mounted mobile base station to provide services like file distribution among group communications over heterogeneous architecture with the aid of group application server and Proximity Service links as illustrated in Fig. 1. In this solution, a vehicle-mounted mobile base station is placed close to the disaster area and works in a cell breathing manner to expand or shrink the cell coverage periodically to support group communications. In [11], author use the multi-hop function where a device can play the role of a relay to connect out-of-range devices using D2D connection. Thanks to the Third Generation Partnership Project (3GPP) that proposed this D2D technology coupled with the Proximity Service (ProSe) [8]. Thus, ProSe technology allows UEs in proximity to discover themselves and even to have a direct communication as soon as telecom operators enable the public safety mode. Direct links are then created between UEs rather than having their radio data (user plane) travel through the base station (BS) or over the core network. D2D communications can effectively improve overall throughput, minimize packets latency/jitter as well as optimize radio spectrum utilization and even energy consumption. The next section explores how to use D2D and ProSe technology to build underlay networks.

III. UNDERLAY D2D NETWORK BASED ON PROSE SERVICE

A. Introduction

During the first generations of cellular networks, only one air interface is defined and used to connect UE to the network infrastructure by supporting *uplink* and *downlink* operations. With the 3GPP release 12[3], a *sidelink* has been introduced allowing UE to connect directly with other UEs. This *sidelink* defines a set of physical, transport and logical channels that can be deployed for synchronization, discovery, and direct communication operations within D2D communication. Newly defined physical layer channels are as follows:

- *PSBCH:* Physical SL broadcast channel, which carries system information and synchronization signals.
- *PSCCH:* Physical SL control channel, which carries UE-to-UE control plane data.
- *PSDCH:* Physical SL discovery channel, which supports UE direct discovery transmissions.
- *PSSCH:* Physical SL shared channel, which is used for user plane data transmission.

B. Reference ProSe architecture

3GPP has also defined a Proximity Service (ProSe) in both 4G[4] and 5G[12]. From Fig. 2, some main components can be identified:

- *ProSe App server* which can serve as public safety answering point and can directly communicate with an application defined in UE.
- *ProSe UE App* which is an application installed on the UE side that uses ProSe capabilities.
- *ProSe Function/DDNFM* that acts as the reference point for *ProSe App Server* and UEs. This function is responsible for verification, authorization, and configuration of UEs. It also allows network core level discovery for direct communication scenarios between devices.

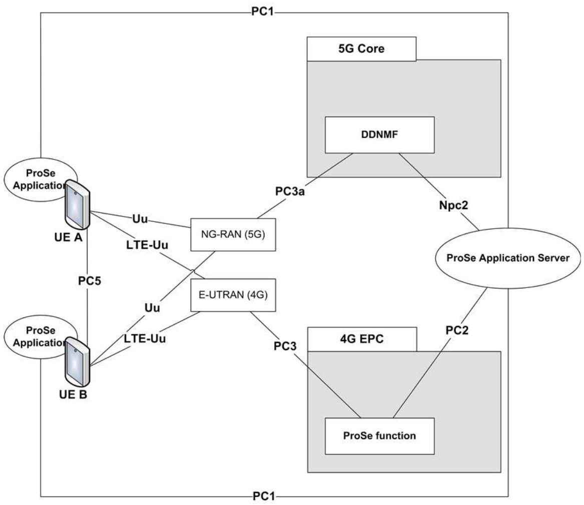

Fig. 2. Non-Roaming reference ProSe architecture for 4G/5G networks

In addition to the PC5, several other interfaces have been defined by 3GPP to allow interaction between the various ProSe components and network core functions. We can mention the PC1 interface that enables applications installed on the UE to exchange data with the ProSe Server while the PC2 is used by ProSe functions to get updates from the server and to support all functionalities used for direct D2D communication. On the other side, the UE can use the PC3 interface for D2D discovery and communication.

The architecture presented in Fig. 2 shows a basic case of two UEs belonging to the same public land mobile networks (PLMN) supporting 4G and 5G networks. However, it is possible that UEs register to different PLMNs or even belong to different radio access networks (RANs) such as LTE-A and WiFi. Some other interfaces not mentioned in this paper can be used for roaming scenarios to keep home *ProSe*

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function/DDNFM reachable for both the roaming UE as well as the visiting *ProSe function*.

C. *ProSe functions and communication scenarios in public safety networks*

In public safety context and following any eventual damage caused by the disaster, three situations can be resulted: (1) cellular antenna continue to operate normally, (2) a part of them are available while other are paralyzed, and (3) all the access network is paralyzed. To support these cases, D2D communication can be divided according to the following three scenarios, as shown in Fig. 3:

- In-coverage: when all UEs are within eNB coverage.
- Partial-coverage: when at least one in-coverage participant acts as UE-to-Network relay while other UE-to-UE relays can provide access to distant users.
- Out-of-coverage: when all participants are out of the eNB's

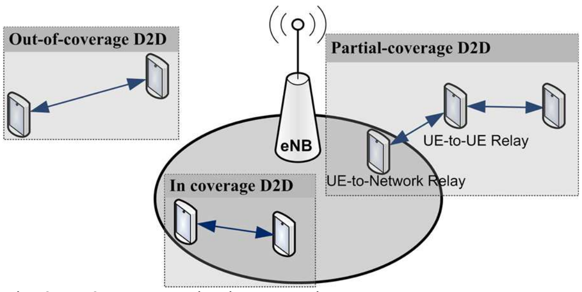

Fig. 3. D2D communication scenarios

Fig. 4 illustrates all supported ProSe functions and scenarios for both commercial and public safety use cases. While only ProSe discovery operations are supported in commercial context, the Public Safety can benefit from all available ProSe functions including direct and relay-based communication through PC5 interface. We note that WLAN integration is defined only in ProSe based on LTE, while the UE-to-UE Relay function is defined only in ProSe based on 5G network.

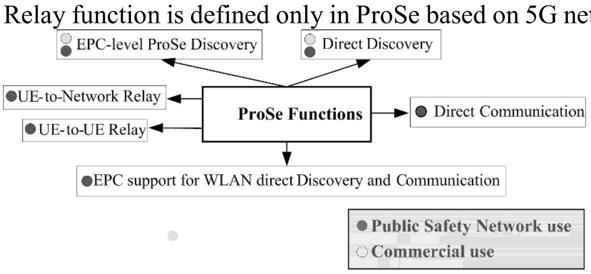

Fig. 4. ProSe functions overview.

D. *D2D synchronization procedure*

Synchronization procedure is a precondition for direct communication and direct proximity discovery services. This procedure defines physical resources in time and frequency that carries D2D control and traffic data. The Primary Sidelink Synchronization Signal (PSSS) is deployed in synchronization of the initial timing and frame boundary estimation. PSSS signals are designed to simplify the detection of the synchronization sources. It can be broadcasted by cellular antenna for in-coverage UEs or even by an independent UE for partial and out of coverage scenarios. The synchronization procedure happens naturally as long as UEs are in coverage of the same eNB or scattered over synchronized neighboring eNBs. For UE located in coverage of an eNB that supports *sidelink* operation, Resource Pool with preconfigured list of Transmission and Reception parameters will be provided to configure the D2D direct communication.

E. *Infrastructure vs. D2D based communication*

Despite all efforts to execute load balancing between cells, the fully centralized approach based on eNBs is not usually suited for public safety situations where large number of subscribers are grouped on the same area and sharing large amount of data. To avoid eNBs overload situation, D2D direct communication can be considered as an alternative solution that creates an underlay network supported and maintained by participant UEs as illustrated in Fig. 5. All the traffic should then be spread among the involved devices throw direct communication links. Moreover, partial-coverage D2D communications can be deployed to overcome lack of coverage issue.

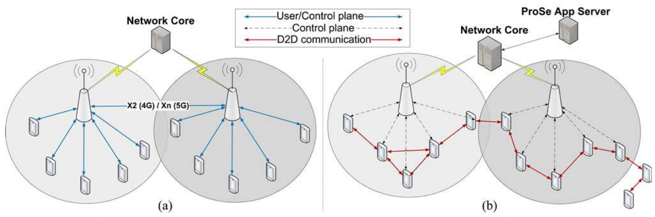

Fig. 5. Infrastructure vs. D2D based communication in cellular networks. (a) Underlay network in cellular network. (b) Underlay network in D2D.

F. *Underlay D2D topologies Models*

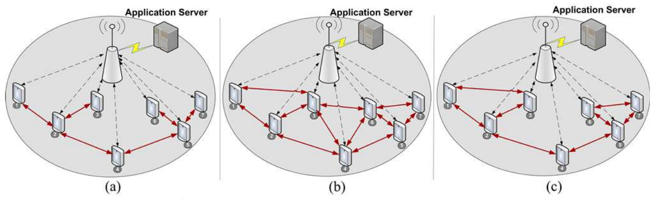

Fig. 6. Overview of some D2D underlay network topologies Models: (a) Loosely Coupled, (b) Fully Coupled, and (c) Tightly Coupled.

ProSe Direct D2D communication can be established through one-to-one or one-to-many methods [3]. Users in coverage receive authorization and radio parameters from the PLMN while out-of-coverage users should use their pre-configured data. The one-to-many communication is based on multicast method to enable subscribed users having the same Group-ID to receive a copy of the message. In D2D communications, links quality is evaluated according to the channel Quality Indicator (CQI) by attributing a value between 1 and 15 [13]. These values indicate the level of modulation and coding the UE could operate. The value 15 is assigned to the channel having the best quality. In this work, we define some D2D models according to the following topologies illustrated in Fig. 6:

- Loosely coupled: In this model, illustrated in Fig. 6(a), a minimum number of links should be created and maintained within D2D group using one-to-one communication method.
- Fully Coupled: In this model illustrated in Fig. 6(b), each UE should connect with all neighbors in its range. This approach can be achieved using multicast one-to-many communication method.

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- Tightly coupled: In this approach illustrated in Fig. 6(c), starting from the loosely coupled model, new additional selected links can be added between UEs according to one of these strategies: (1) based on CQI by maintaining only links that hold certain CQI threshold, (2) based on a maximum number of links per user in manner to connect with neighbor having less number of connections instead of neighbor with highest CQI, and (3) based on a combination of the two previously mentioned strategies while the additional links are both limited by their number but also by the minimum level of CQI.

IV. The D2D Loosely coupled Model

This paper will focus on the loosely coupled that keep a minimum number of direct connections between UEs while guaranteeing an interconnection path between the maximum number of participants.

A. *Neighbor's classification*

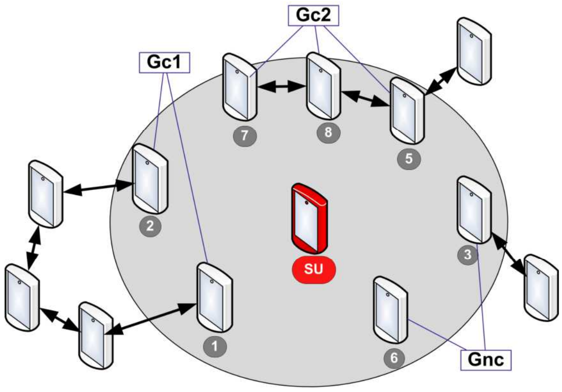

Fig. 7. Create Gnc and Gc groups for users in-coverage of Selected User.

To facilitate the management of the network, each Selected User (SU) will detect neighbors in his coverage and classify them according to two possible group types: The first single group, named *Gnc* (Group of not connected), which includes all the neighbors who have no path connecting them. The second group type is named *Gc* (Group of connected). Depending on the topology, some Gc groups can be created to include all the *SU* neighbors who have an already path that connects them. If many groups are created, they will be named *Gc1*, *Gc2*, *Gc3*, etc. We mention that the path which connects two neighbors can allow either a direct link or indirect link between them by crossing other UEs who are not necessarily neighbors of the *SU*. Based on the example illustrated in Fig. 7, the SU should create the following groups: *Gnc* = {3,6}; *Gc1* = {1,2}; *Gc2* = {5,7,8}.

B. *Adding user to the network*

To join a D2D network, the new user (NU) starts by sending a PSCCH message to discover his neighborhood. Based on PC1 interface, ProSe Application Server should provide to the NU a global description about the participating UE including an identification of interconnection links. Based on this information, NU should be able to create Gnc and Gc groups to classify discovered users on the neighboring. As a next step, as illustrated in Fig. 8 and Fig. 9, NU should create a direct communication using PSSCH with all neighbors on the Gnc group. Afterwards, direct communication should be established by NU with the user having the best CQI on each Gc group.

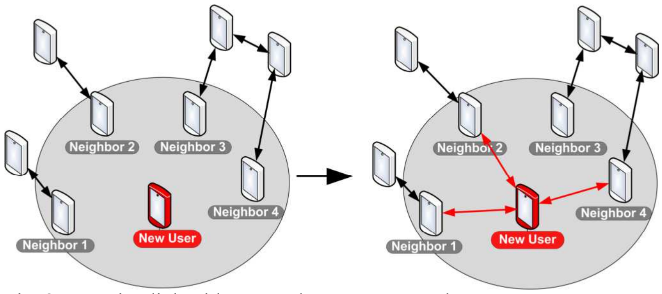

Fig. 8. Creating link with Gnc and Gc groups members.

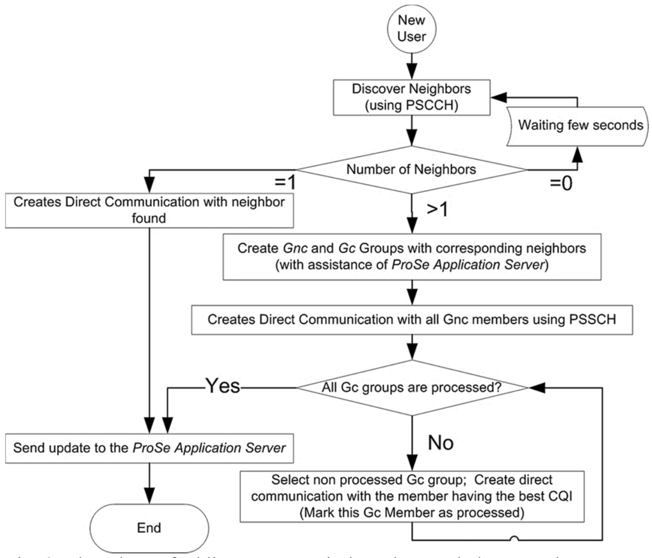

Fig. 9. Flowchart of adding new user in loosely coupled approach.

C. *Network Update Management*

The geographic mobility of UEs, combined with different obstacles and external sources, can significantly affect the power and quality of the signal. In this context of permanent change of CQI, it is important to conduct periodic updates to ensure the connectivity of the group. Two strategies are proposed: (1) *Less cost approach* that tends to retain the links between UEs as long as they exist. However, as soon as a link from a member of the *Gc* group is lost, a new link with a UE from the same *Gc* group will be created, (2) *Optimized tree approach* that is a little more expensive, but it has the advantage of guaranteeing a network with optimal links. As soon as a variation in the link with a member of one of the Gc groups is detected, the procedure is triggered to check if a better link is possible within the same group. The two approaches are illustrated on the flowchart of Fig. 11.

D. *UE departure or disconnection*

UE disconnection from the D2D network can be done according to three different scenarios:

- Alert before leaving: Alert can be generated by the UE before leaving the D2D network. This can happen when the battery reaches a critical level, or as soon as the CQI level drops continuously and tends towards

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zero, or if the user sends a disconnection request before closing the application.

- Suddenly without alerting: This situation should not be very frequent, and it is due to a voluntary closure of the terminal connection or due to signal interference. Otherwise, it could be caused by an obstacle which suddenly blocks the radio transmission.
- General disconnection from the network: When the rescue mission ends, the PLMN terminates the public safety network mode. In this case, the UE is no longer authorized to use direct D2D communication function.

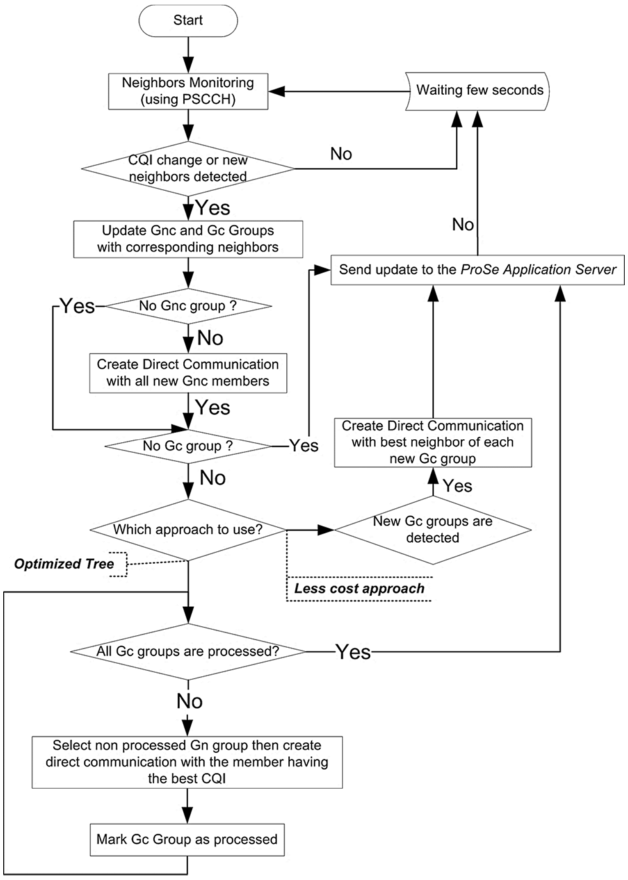


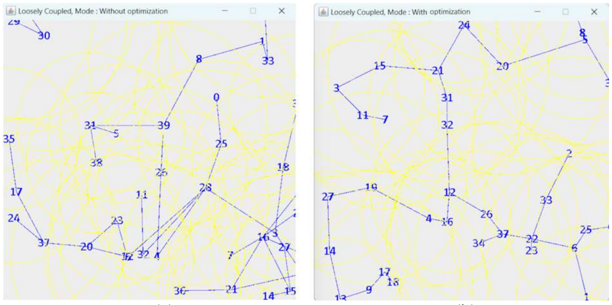
Fig. 10. Flowchart of network update procedure.

Depending on the position on the topology, if the UE was a "Leaf node" (holding only one connection), in this case, no damage to the network tree can be caused by this departure. For other cases, D2D network using the loosely coupled approach will be affected and recovery procedure should then be launched in proactive or reactive mode to find alternatives. Fixing CQI threshold close to value 1 or 2 can, in many cases, resolve the departure problem by proactively changing the network topology in manner to place the UE as leaf node.

V. Simulation Environment and Parameters

A. *Introduction*

We have developed our own Java based simulator [14]with graphic interface using MG2D API [15]. The loosely coupled model has been implemented to support both ‘less cost” and “optimized tree” algorithms as illustrated in Fig. 11. Simulation parameters presented in TABLE I are used during the simulations.



(a) (b)

Fig. 11. Overview of loosely coupled topology implementing (a) “less cost” and (b) “optimized tree”.

TABLE I. Summary of the Parameters used in the simulation experiments.

Simulation Parameters	**Value**
Transmitter range	Randomly from 100 to 200 m
CQI	[1 to15] (0 for unreachable UE)
Simulation Time	7200 seconds (2 hours)
Node Pause Time	Randomly [0, 60 seconds]
Topology Size	500 x 500 m^2
Number of Nodes	*From 2 to 70 (new node every 100 seconds)*
Node Speed (V)	*From 1 to 4 m/s*

B. *Adding users to the simulation area*

Number of nodes representing UEs can then be placed randomly on preconfigured square/rectangle area. Once the total number of UE nodes in the simulation is defined, it is possible to add all the UEs either during simulation launch, or gradually according to pre-configured time intervals. In our simulations, we opted for the second method by adding a new UE every 100 seconds. This allows better analysis of the group evolution according to the number of participants as well as many parameters related to the connectivity levels, the average CQI and the number of topology updates.

C. *UE movement model*

RDM (Random Direction Mobility) model, described in [[16], is used to simulate rescue team movements during the disaster situation as illustrated in Fig. 12. Compared to other models, RDM avoids a high probability of any node to select a new destination located around the center of the simulation area, or a destination that requires path of the node through the center area. In our simulation, a node starts its motion by selecting a direction [0, 2*π] with speed [0, V. As soon as the node reaches the limit of the simulation zone, it waits for a random pause time of [0,60s]. Subsequently, the node chooses a new direction among [0, π] while keeping its initial speed. This process continues until the simulation ends.

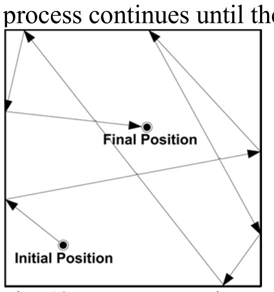


Fig. 12. UE movement in Random Direction Mobility Model.

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D. UE transmission range and CQI calculation

Even if the direct LTE max transmission range can reach 500 meters[17], the realistic values are generally located between 100 to 200 meters [18] depending on the area topology and by taking into consideration sources that can affect signal strength/noise. The uplink CQI is determined proportionally to the distance *d* between the two UEs by considering the maximum transmission range *R* of each user as illustrated in Algorithm 1.

Algorithm 1. CQI calculation.

```
if d > R  then
   CQI ← 0
else if d = = 0 then
   CQI ←15
else
   CQI ← 16 – d / (R / 15)    // CQI is defined as an integer
```

E. Network update based on CQI threshold

It is possible to implement an approach based on CQI threshold as described in Algorithm 2. If a neighbor on the same Gc group offers better CQI, UE will check if this CQI is at least higher than a certain CQI threshold before executing the handover and generating new network topology update. Such an approach could certainly reduce the number of substitution/handover operations and therefore network updates. However, simulations must be carried out to assess the impact on the average CQI among all established links.

Algorithm 2. Network Update Function according to CQI threshold.

```
Set CQI_threshold
For each Gc group of selected UE do
 if CQI(New_neighbor) - CQI(Old_neighbor) <= CQI_threshold    then
    keep Connection with Old_neighbor
  else
   Connect with New_neighbor
   Disconnect from Old_neighbor
   Report the modification to the ProSe Application Server
   number_of_updates ++
 end
end
```

F. Network update based on optimization interval

In the "optimized tree" approach, link optimization, based on CQI comparison, takes place every second. However, it is possible to customize this optimization interval by choosing different interval values. As explained in algorithm 3, with defined optimization interval *i*, this approach will be executed intermittently using either CQI threshold = 15 (corresponding to the "less cost" approach) or a predefined CQI threshold.

Algorithm 3. Network Update Function according to optimization interval.

```
Set optimization_interval to i
if sim_Step % optimization_interval = 0   then
    execute Network update function with defined CQI_threshold
 else
   execute Network update function with CQI_threshold = 15
end
```

VI. Performance Analysis and Results

A. Effects of Density and Group connectivity

In public safety situations, the aim is to guarantee reachability between participating users during the rescue mission. Group connectivity is defined as the capacity of all group users to continue to be inter-connected together and reachable by other members of the same group. Otherwise, the

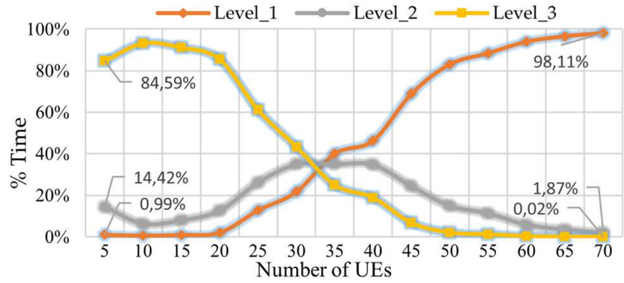

Fig. 13. Progression of the three Group connectivity levels according to the number of UEs and the corresponding time duration in percentage.

consistency of group connectivity is not usually guaranteed, especially when a limited number of UEs, having different rescue missions, should move in opposite directions. We define three levels of group connectivity: *level_1* when all users participating in the mission are reachable by forming a single group, *level_2* when 2 groups of users are formed, and *level_3* when 3 groups or more are formed. Fig. 13 depicts the progression of the three levels of connectivity according to number of UEs using simulation parameters presented in TABLE I. For each selected value of UEs from [5 to 70] placed on a square area of 500 m² with a random speed that varies from 1 to 4m/s, we calculate the average value of 10 simulations of 7200 seconds.

During these simulations, a verification is processed every second to count the time duration corresponding to every formed group's connectivity type. For better presentation, we express the resulted time as a percentage of the total simulation time duration. From Fig. 13, it is possible to conclude that with less than 20 UEs (80 UEs/km²), the probability of having a single group (or even two) is very low. From 50 UEs (200 UEs/km²), the probability of having level_3 become very minimal. As soon as 70 users (280 users/km²) are reached, the uniqueness (level_1) of the group is confirmed and the division of this group occurs for less than 2% of the total time, i.e., up to 2 to 3 minutes every 2 hours.

B. Less cost vs. optimized tree approaches

Using the simulation values presented in Table I, the two approaches "less cost" and "optimized tree" are implemented. Simulations are conducted to estimate how costly keeping an optimized topology could be in terms of links substitutions/updates. Fig. 14 illustrates the gap between the two approaches that becomes more considerable once the number of users reach 20. From 30 users, the gap becomes more stable with 2 to 3 points on the CQI scale. The measured CQI value represents the average according to the CQI of all established direct communication links of the network. On the.

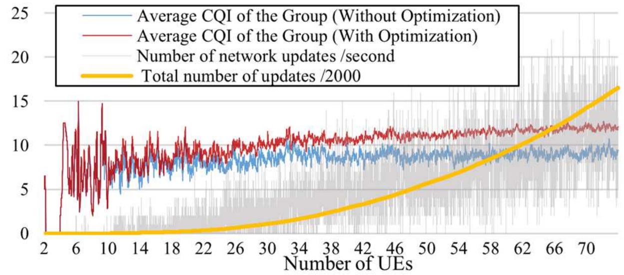

Fig. 14. Comparison of "less cost" vs. "optimized tree" approaches in terms of average CQI with the progression of both number of updates per second and total number of updates while number of user increase.

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same graph, a total incremental number of updates (divided by 2000 for better visibility) as well as periodic number of updates per second have been added. We notice that their value increases exponentially while the number of active users is in linear progression. With 70 UEs, it takes up to 25 operations per second to keep the network optimized. During 2 hours of simulation, more than 32,000 operations of network update were performed.

C. *Effect of CQI threshold based approaches on network updates and average CQI of the group*

To reduce the number of network updates generated by the “optimized tree” approach, we introduce a CQI threshold that should be verified before performing the update. Several CQI thresholds were used during the simulations ranging from 0 (for the optimized approach) up to 10. From Fig. 15, we can notice a gain of almost 30% of network updates when the CQI threshold is egal to 1. This gain continues to progress less significantly with increasing CQI threshold values.

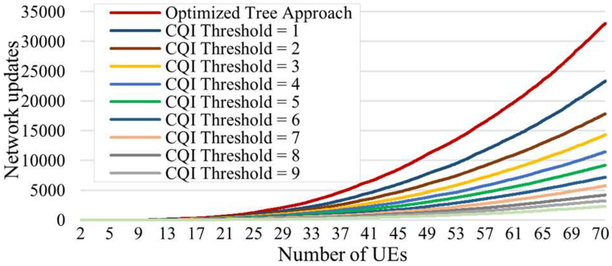

Fig. 15. Number of network updates generated according to different CQI thresholds.

For each number of users grouped by 10, we calculate the gain generated in terms of the average CQI according to simulated CQI threshold values. As a reference, the gain of 100% is obtained with the “optimized tree" method while 0% is the result of “less cost” method. Fig. 16 shows outstanding results with 95% of gain when CQI threshold is equal to 1. With CQI equal to 2, the gain becomes slightly less stable by depending on the number of users and varying from 88% for 60/69 UEs up to 82% for 10/19 UEs. In these simulations, results when number of users is less than 10 are not represented since we found the resulted average CQI extremely unstable.

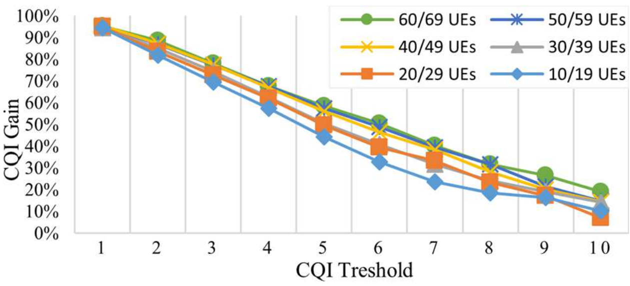

Fig. 16. Average CQI gains according to the number of UEs and CQI threshold values.

D. Effect of increasing optimization intervals on network updates and average CQI of the groupe

With the aim of reducing the number of network updates, a set of simulations is achieved by increasing the optimizations interval while CQI threshold is fixed to 0. Instead of performing the optimization every second, different values of

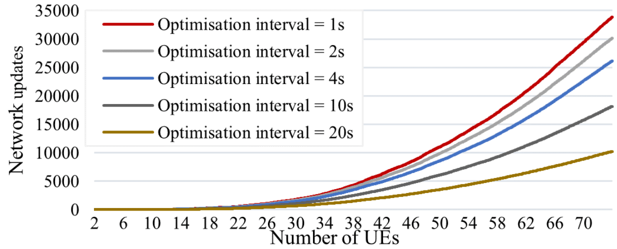

Fig. 17. Number of network updates generated according to different optimization intervals.

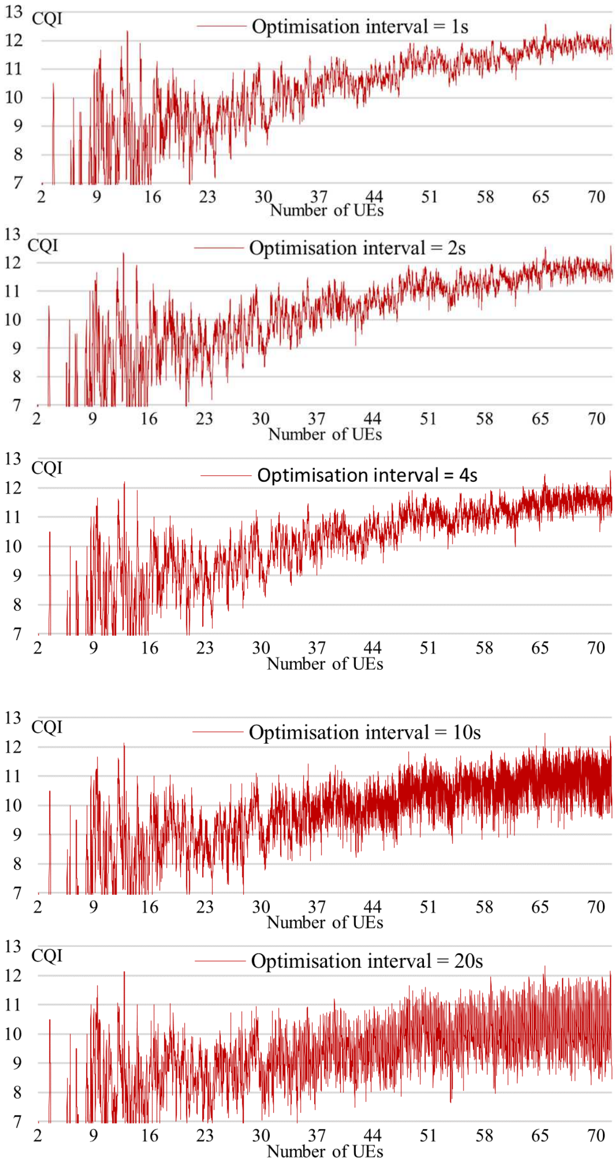

Fig. 18. Resulted average CQI according to different optimization intervals.

the optimization interval (2, 4, 10 and 20 seconds) were simulated. Compared to the “optimized tree” where optimization is carried out every second, Fig. 17 show that using an interval of 2 seconds can reduce the number of network updates by almost 10% when the number of UEs exceed 50. We notice that the gap between network updates becomes more significant from 40 UEs. Moreover, as the number of UEs increases, the reduction in network updates continues to decrease.

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By using the same values of the optimization interval, a set of simulations was carried out to verify the effect on the average CQI. From Fig. 18, different graphs corresponding to selected optimization interval value are represented. We notice that the shape of the graphs lines in the upper part are almost close to those of the "optimized network" approach. However, the difference widens in the lower values of the graphs which drops significantly when the optimization interval increases, approaching the values obtained with the "less cost" approach.

E. *Effect of the combination of the CQI threshold and the optimization interval compared to the "optimized tree" approach*

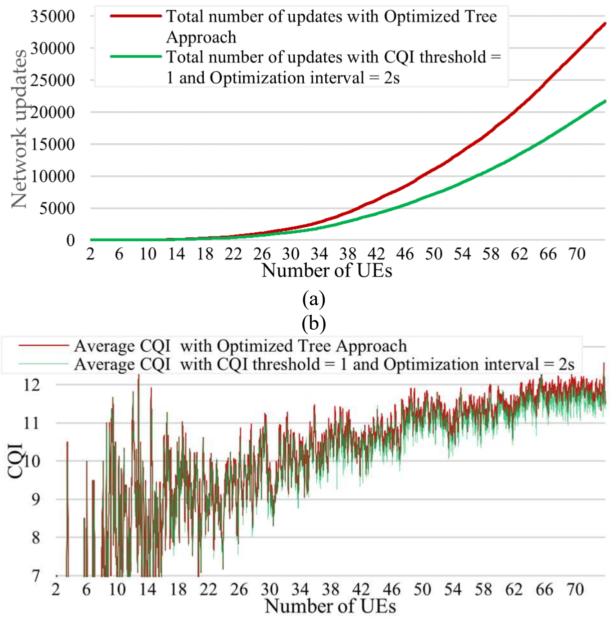

Fig. 19. Effect of optimized tree approach and customized approach (CQI threshold = 1 and optimized interval = 2s) on (a) the number of network updates and (b) average CQI.

During the series of simulations previously presented, it was possible to observe that the use of low valuers of CQI threshold or optimization interval made it possible to reduce the number of network updates without significantly affect the CQI average. By combining these two parameters : CQI threshold = 1 and optimization interval = 2 seconds, new simulations were therefore carried. From results presented in Fig. 19, we can notice a considerable drop in the number of updates while the average CQI has been slightly degraded.

VII. Conclusion

D2D is a promising technology that opens the doors for different service use cases mainly during emergency situations where direct communication is enabled by telecom operators. Through the simulations, it was possible to define the required UE density level that guarantees global connectivity for all participating users in the loosely coupled model. Both of “optimized tree” and “less cost” approaches were evaluated in terms of the number of network updates and the level of the average CQI. It was concluded that the use of a CQI threshold equal to 1 combined with an optimization interval equal to 2 seconds can considerably reduce the number of optimizations updates while average CQI is kept close to the maximum values.

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