Enhanced Transmission Algorithm for Dynamic Device-to-Device Direct Discovery

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***Abstract*—In order to support the increasing demand for capacity in cellular networks, Long Term Evolution (LTE) introduced Proximity Services (ProSe) enabling Device-to-Device (D2D) communications, defining several services to support such networks. We are interested in the performance in out-of-coverage scenarios of one of these services: direct discovery. As defined in the standard, network and configuration parameters for direct discovery are predefined and do not change over time, which creates an inability to adjust to variations in topologies, number of operating devices, and/or users' mobility during the discovery process. In this paper we propose an enhanced discovery algorithm that, building on previous works, allows users to adapt to potential variations in the discovery group, using optimized transmission probabilities and transmission success probabilities. The performance of this algorithm is evaluated, and we demonstrate gains in the accuracy of the discovery information, and in the time required for discovery.**

***Index Terms*—Long Term Evolution (LTE), Device-to-Device (D2D), D2D Discovery, Proximity Services (ProSe), Simulations, Performance, Algorithm**

I. Introduction

Long Term Evolution (LTE) cellular networks rely on infrastructure nodes, such as Evolved Node B (eNB), Mobility Management Entity (MME), Serving Gateway (SGW), and PDN (Packet Data Network) Gateway (PGW) to manage the communication and network access by the users. This architecture simplifies the administration of the resources and allows for an accurate understanding of the status of the network as a whole by the entities granting access. However, this means that coverage and service quality are dependent on the existence of supporting infrastructure. In order to increase coverage, provide service in areas without access to infrastructure, and improve the quality of service in saturated areas, the Third Generation Partnership Project (3GPP) introduced Proximity Services (ProSe) using different mechanisms (discovery, synchronization, direct communication) to allow devices to communicate directly [1]. Several different operating modes have been defined to account for situations where User Equipment (UE) have access to infrastructure that will arbitrate the in-coverage or out-of-coverage communication, thus allowing the UEs to select the resources used for communication themselves. In the out-of-coverage case, the parameters that the UEs shall use for communicating (e.g. the number of physical resources to use, the length of the period, etc.) are preconfigured in the devices and are not modified during operation, meaning that the devices can not adapt to the actual network conditions to make an efficient use of the available resources.

In this paper, we make the UEs aware of the network conditions (e.g. number of UEs) using the messages from the discovery service. This in turn allows us to improve the use of resources and reduce the time required to complete the discovery of all the UEs in the group. The proposed algorithm allows UEs performing discovery to detect the presence and the withdrawal of other UEs in the discovery group.

This rest of the paper is organized as follows. In Section II, we discuss the related work in D2D discovery. In Section III, we present our proposed transmission algorithm that takes into account success probabilities and recognizes both UE arrivals and departures. Performance evaluation and simulation results are described in Section IV. Finally, we conclude our work in Section V.

II. Related Work

Existing research on D2D Discovery has focused on the modeling and performance of network assisted discovery (that is, D2D discovery for in-coverage scenarios, where the eNB controls the process). For example Madhusudhan et al. study the performance in terms of throughput of network-assisted discovery in [2]. Xenakis et al. [3] study and provide analytical models for the number of UEs and their deployment in a group for discovery to perform optimally. Similarly, Chour et al. in [4] offload the discovery process from the LTE UEs to Vehicular Ad-hoc Network (VANET) nodes (like roadside units), and Albasry and Ahmed in [5] propose power control strategies to minimize interference and noise.

Regarding the D2D discovery process without network intervention (D2D direct discovery), we can find some works in the literature exploring the architecture design: Sharmila et al. in [6] propose an alternate framework to that of 3GPP's that extends the services available for the UEs, and Murzak et al. in [7] look into the potential of direct discovery for interconnecting LTE and 5G networks.

There has been some work on optimizing the D2D direct discovery, in particular the work by Griffith and Lyons [8]. The authors computed the optimal value of the discovery message transmission probability that minimizes the mean number of periods required for all members of a group of UEs to discover each other. Based on this work, an adaptive algorithm is proposed in [9]. The discovery process in LTE D2D out-of-coverage scenarios is improved by dynamically adjusting the transmission probability to the optimal value as defined in [8]. Therefore, the algorithm gives the UEs the ability to change their transmission probabilities as needed to reduce the time required to discover other UEs. However, that algorithm is able to detect UEs joining the group at any time of the discovery process, but it does not take into account UEs leaving. In this paper, we enhance that algorithm using the probability of a message reception in a given time interval to learn how long a UE should wait before assuming that another UE has left the group, enabling the devices to fully adapt to dynamic scenarios. To the best of our knowledge, this is the only research available that allows the UEs to learn and adapt the size of the discovery group over time, and adapt the transmission parameters accordingly.

III. Enhanced Transmission Algorithm

In Table I, we provide a list of symbols we use in this paper.

TABLE I: List of Symbols

Symbol	Definition
N_f	Number of resource block pairs available for discovery
N_t	Number of subframes available for discovery
N_r	Total number of resources in discovery pool
N_u	Total number of UEs in the scenario
UE_X	Randomly chosen UE
θ_i	Received transmission probability of UE_i
θ_{tx}	Transmission probability of the transmitter UE_{tx}
θ_{rx}	Transmission probability of the receiver UE_{rx}
θ_{ini}	Initial transmission probability for the 3GPP algorithm
n_{min}	Minimum number of periods before assuming a UE is gone
p	Success criteria (i.e. confidence) value
t_i	Time of the last reception of UE_i

A. Optimal Transmission Probability

In the standard, all UEs announce using a preconfigured transmission probability defined in the discovery resource pool for UE-Selected mode. However, based on [8], the use of specific transmission probability values selected according to the size of the group improves the performance of the whole process significantly. The optimal transmission probability θ^* is calculated as shown in Eq. (1), except when Eq. (2) is true, in which case the optimal value of θ^* is 1.

$$\theta^* = \frac{2N_r+N_t(N_u-1)-\sqrt{4N_r(N_r-N_t)+N_t^2(N_u-1)^2}}{2N_u} . \quad (1)$$

$$N_u < \frac{N_r(N_t-2)+N_t}{N_t-1} , \quad \text{where} \quad N_t > 1 \quad (2)$$

Although the computed value θ^* is not necessarily a multiple of 1/4 (as recommended by 3GPP), it was shown that rounding up to the next allowed value (i.e. 0.25, 0.5, 0.75, 1) does not alter the discovery performance. Therefore, from now on, we will be using θ as the approximation of θ^* to the nearest non-zero multiple of 0.25 less than or equal to 1.

B. Success Probability

A discovery message is successfully received between two UEs if several conditions are satisfied. First, the transmitter UE_{tx} is allowed to announce in the current period after checking its transmission probability θ_{tx}. Secondly, the receiver UE_{rx} should not be announcing at the same time slot (i.e. subframe) or it would miss UE_{tx} discovery message, as the discovery messages are sent over a half-duplex channel, which prevents the UEs from sending and receiving data in the same time slot (half-duplex constraint). Finally, none of the other UEs pick the same resource in the same time slot as the transmitter to avoid any collisions. Accounting for those requirements, the success probability of UE_{rx} discovering UE_{tx} for a **single period** is defined by Eq. (3) for the 3GPP-defined behavior (i.e. static), and by Eq. (4) for the adaptive algorithm (i.e. dynamic) presented in [9].

According to the static 3GPP behavior, all the UEs utilize the initial transmission probability θ_{ini} throughout the whole discovery process. We assume that all UEs have the same θ_{ini}. So, the probability of a discovery message being successfully received is:

$$P_{success_{static}} = \theta_{ini}\left(1-\frac{\theta_{ini}}{N_t}\right)\left(1-\frac{\theta_{ini}}{N_r}\right)^{N_u-2} \quad ; \quad (3)$$

However, using the dynamic adaptive algorithm, we know that each UE_i has its own transmission probability θ_i computed using Eq. (1) and Eq. (2), and from them we derive the probability of success for dynamic values of θ:

$$P_{success_{dynamic}} = \theta_{tx}\left(1-\frac{\theta_{rx}}{N_t}\right)\prod_{i\neq tx, i\neq rx}\left(1-\frac{\theta_i}{N_r}\right) ; \quad (4)$$

The resource pool parameters N_r and N_t are known and constant. Knowing that, we use Eq. (3) and Eq. (4) to calculate the probability of a successful reception within n periods, which is:

$$p = 1-(1-P_{success})^n \; ; \quad (5)$$

Eq. (5) allows us to determine the minimum number of periods for a UE to receive an announcement from another UE, given a success criteria equal to p.

$$n_{min} = \frac{\ln(1-p)}{\ln(1-P_{success})} \; ; \quad (6)$$

With these models it is possible for the receiver to know how long it should wait before learning that a transmitter has turned off or moved away, according to the confidence (i.e. the success criteria) on that learning that is desired or required.

C. Redesigned Discovery Message

In order to be able to make use of those analytical models in the discovery process, we need to announce each UE's transmission probability. To do so, we will introduce a minor modification in the discovery message format. The most significant component of the discovery message is the ProSe Application

Code (with a size of 184 bits [10]). This code is allocated per announcing UE and application and has an associated validity timer. Discovery messages are limited in size (only 232 bits) to allow their transmission in a single subframe and a pair of resource blocks, even in bad channel conditions. Increasing its size is not a practical option because that will be resource-consuming and shrink the available bandwidth. To overcome this limitation and to avoid unnecessary overhead, our proposal allocates 2 bits of the ProSe Application ID Name, within ProSe Application Code, to carry the value of the probability of transmission in the form of two coded bits for the four allowed values for θ (i.e. 0.25, 0.5, 0.75, 1).

Using this approach, we maintain the size of the ProSe Application Code, as shown in Fig. 1. A mapping example of the 2-bit values is presented below:

- 0.25: 00
- 0.50: 01
- 0.75: 10
- 1.00: 11

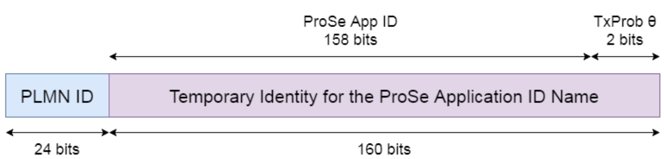


Fig. 1: Modified ProSe Application Code

D. Proposed Algorithm

Given that 3GPP does not define how the detection of departing UEs should happen, we will be testing an implementation similar to the one in our enhanced algorithm. Therefore, the only differences between both implementations (static, i.e. 3GPP defined with our departure detection mechanism, and dynamic, i.e., our proposed enhanced algorithm) will be the use of the optimal theta and keeping track of the individual values of θ.

For any given UE$_X$, the transmission process for D2D direct discovery in UE-Selected mode will follow either Algorithm 1 or Algorithm 2 depending on whether we are using the 3GPP-defined transmission probability or the enhanced algorithm. The discovery period length, the number of subframes and resource blocks dedicated to discovery, and the considered success probability are the inputs to both algorithms.

Using the modified version of the 3GPP algorithm (Algorithm 1), each UE will keep track of UEs it discovered and the time they were discovered, and will update the number of UEs discovered based on both Eq. (3) and Eq. (6). It will be referred to as static configuration because θ does not change throughout the simulation.

For the enhanced algorithm (Algorithm 2), each UE will be able to process the received announcements, check which ones are new or contained a different transmission probability, and

Data: d is the discovery period length in seconds
and p is the considered success criteria
for *any given UE$_X$ performing D2D discovery* **do**
  UE$_X$ receives discovery messages from n UEs;
  Record current time as *TimeNow*;
  for i *in* $[1, n]$ **do**
    if *UE$_i$ was never discovered before* **then**
      Create record for UE$_i$;
      Set $t_i = TimeNow$, where t_i is the time of most recent reception from UE$_i$;
    else
      Update UE$_i$'s record: set $t_i = TimeNow$;
    end
  end
  for *each UE$_j$ received so far* **do**
    calculate n_{min} based on all the received transmission probabilities (Eq. (6));
    if $n_{min} < \frac{TimeNow - t_j}{d}$ **then**
      Delete UE$_j$'s record;
  end
end

Algorithm 1: 3GPP transmission algorithm (Static) using success probabilities for D2D Discovery

compute its own transmission probability after discarding UEs that may have left the discovery group using Eq. (1), Eq. (4), and Eq. (6). It will be referred to as dynamic configuration because of the continuous calculation of θ.

IV. Simulation and Results

In this section, we provide the scenarios parameters and simulation results. To obtain the results presented here we used the discrete event simulator ns-3 [11] with the LTE D2D models from [12], extended to include our discovery algorithms.

We define arrival and departure scenarios where UEs join and leave the discovery group throughout the simulations. Users are deployed randomly within an area of 200 m $\times$ 200 m. All UEs are able to discover each other. Each UE sends discovery messages by independently choosing a resource from a discovery resource pool using the procedure in [13]. Table II contains a list of simulation parameters and their default values.

Based on this scenario parameters and according to Eq. (1) and Eq. (2), the optimal transmission probability depends on the number of UEs as represented in Fig. 2.

A. Arrival Scenario

First we will look at an scenario with UEs only arriving to the group. With this scenario we will validate that the modifications introduced in the discovery algorithm do not alter the behavior observed in our previous proposal ([9]). We assume that we have X initial UEs in the area. Their number varies from 10 to 90. After 100 seconds (i.e. 306 periods), Y

Data: d is the discovery period length in seconds and p is the considered success criteria

for *any given UE$_X$ performing D2D discovery* **do**

    UE$_X$ receives discovery messages from n UEs;
    Record current time as *TimeNow*;
    for i *in* $[1, n]$ **do**
        if *UE$_i$ was never discovered before* **then**
            Create record for UE$_i$;
            Set $t_i = TimeNow$, where t_i is the time of most recent reception from UE$_i$;
            Set the transmission probability θ_i;
        else
            Update UE$_i$'s record: set $t_i = TimeNow$ and θ_i;
        end
    end
    $N_u = 1$;
    for *each UE$_j$ received so far* **do**
        calculate n_{min} based on all the received transmission probabilities (Eq. (6));
        if $n_{min} < \frac{TimeNow - t_j}{d}$ **then**
            Delete UE$_j$'s record;
        else
            Increment N_u;
        end
    end
    if $N_u > 1$ **then**
        calculate θ based on the new N_u value, and the pool configuration (N_t and N_r) (Eq. (1)) ;
        round θ to the nearest multiple of 0.25;
        add the encoded value to next announcements;
        use the resulting value of θ to announce;
    end
end

Algorithm 2: Enhanced transmission algorithm (Dynamic) using success probabilities for D2D Discovery

TABLE II: Simulation Parameters and Values

Parameters	Values
UE transmission power	23 dBm
Propagation model	Cost231 [14]
Available bandwidth	50 RBs
Carrier frequency	700 MHz
Discovery period d	0.32 s
Number of retransmission	0
Number of repetition	1
Number of resource block pairs N_f	6
Number of subframes N_t	5
Total number of resources N_r	30
Area size	200 m $\times$ 200 m
Success criteria p	0.99, 0.95, 0.90
Total simulations per scenario	100

UEs join the group, such as $X + Y = 100$ after 100 seconds (i.e. 306 periods).

Using 3GPP algorithm (i.e. static), the discovery performance varies based on the pre-configured (3GPP-defined) transmission probability used. Using our enhanced algorithm

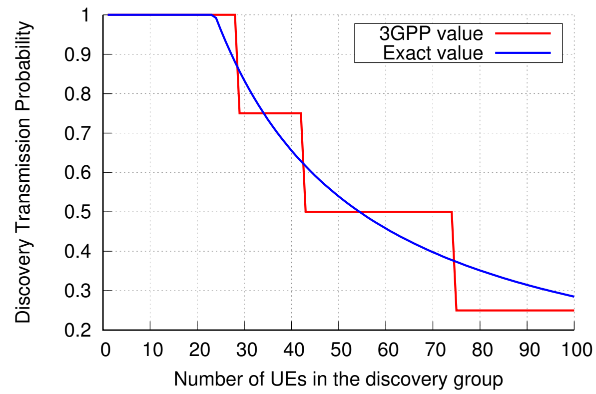


Fig. 2: Optimal transmission probability associated with the number of UEs

(i.e. dynamic), the UEs start announcing using a transmission probability equal to 1 (i.e. 100 %) until they start monitoring discovery messages and use the adaptive algorithm to evaluate the optimal transmission probability value. The second group starts discovery at 100 s (i.e. 306 periods, enough time so that all the UEs in the first group have discovered everyone else in that group). For example, if we have 90 UEs initially, 10 UEs will join later on. We consider a success criteria of 99 % and we compute the number of periods needed for all UEs to discover all other UEs in their own group and the second group, along with a confidence interval of 95 %. Because of the nature of our enhanced algorithm, the number of periods needed to complete discovery is effectively independent of the initial transmission probability used.

We will look at the results of the UEs in group one (1) discovering the UEs in group two (2), and the UEs in group two discovering everyone in Fig. 3 and 4. The legend refers to the number of UEs in group 1. The rest of the cases (UEs in group 1 discovering the UEs in group 1, etc.) are similar to the analyses from our previous paper ([9]), and while we considered and validated that those cases perform similarly, the results are omitted from this paper for brevity.

1) group 1 discovering group 2: We compute the number of periods needed for group 1 to complete the discovery of group 2 in Fig. 3 with 95 % confidence intervals. The UEs in group 1 start discovering UEs in group 2 after 306 periods. The results show that the discovery performance is better when using the enhanced algorithm (dashed lines) in comparison to the 3GPP algorithm (solid lines), independently of the initial transmission probability.

For the 3GPP algorithm, all UEs (from both groups, i.e. 100 UEs) are transmitting at the same initial transmission probability. Based on Fig. 2, the discovery performance is optimal for a transmission probability of 0.25. Therefore, the higher the transmission probability used, the more number of periods needed to finish the discovery. X/Y refers to the scenario where there are X UEs in the first group and Y UEs in the second group. So, we have X UEs discovering Y UEs. The least time needed to finish discovery is when

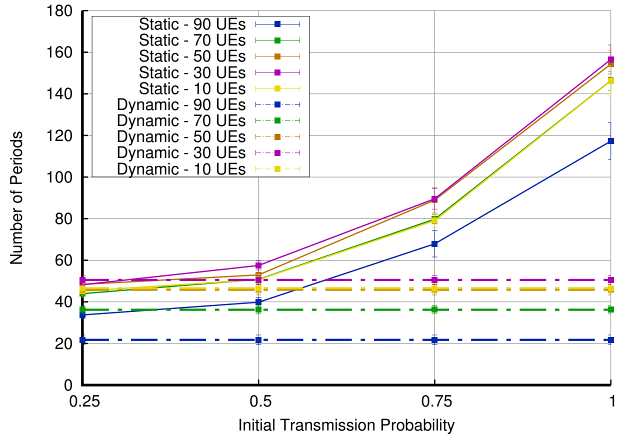


Fig. 3: Number of periods needed for group one to complete discovery of group two, with 95 % confidence intervals

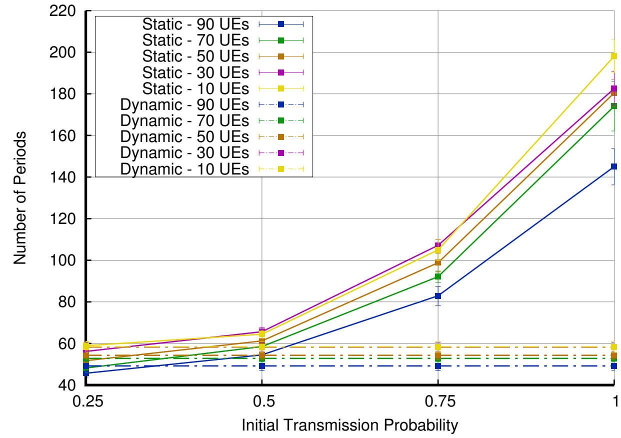


Fig. 4: Number of periods needed to complete discovery by group 2, with 95 % confidence intervals

we have 90/10, i.e. 90 UEs in group 1 and only 10 UEs to be discovered (group 2) by those 90 UEs (blue solid line). However, 70/30 (green solid line) and 10/90 (red solid line) take less time than 50/50 (orange solid line) and 30/70 (purple solid line). In those cases, all UEs in both groups send announcements simultaneously to discover each other, which creates collisions and delays the discovery completion. The delay is related to the number of UEs involved (both the number of UEs performing the discovery and the number of UEs to be discovered). The reason why the 50 and 30 UEs results are worse is that, in the other cases, either the UEs in group 1 were already at a low θ, with a few UEs coming in with $\theta = 1$ initially, which reduced collisions, or the UEs in group 1 were a few UEs with $\theta = 1$, so when group 2 joined, a large number of UEs were discovered in that first period (as everyone is transmitting, all the RBs will be used), and that triggered a quick drop in the value of θ, improving the performance. The results for 50 and 70 UEs show how the "intermediate" values are the ones most likely to be penalized the most by collisions, due to similarly sized groups of UEs having different values of transmission probability (but not 1 or 0.25).

For the enhanced algorithm, as expected, we can see how the initial θ is irrelevant for the results, and only the optimal value of θ for the initial group is a factor that provides different performance. The first group is already using its computed optimal transmission probability. Similarly to the 3GPP algorithm, 90 UEs discovering 10 UEs takes the least number of periods. The UEs in group 2 start using $\theta = 1$ and then adjust it according to the number of UEs they are discovering. Thus the two yellow and green dashed lines are superposed. Finally, the discovery performance for the last two cases (10 UEs and 30 UEs in the first group) is close.

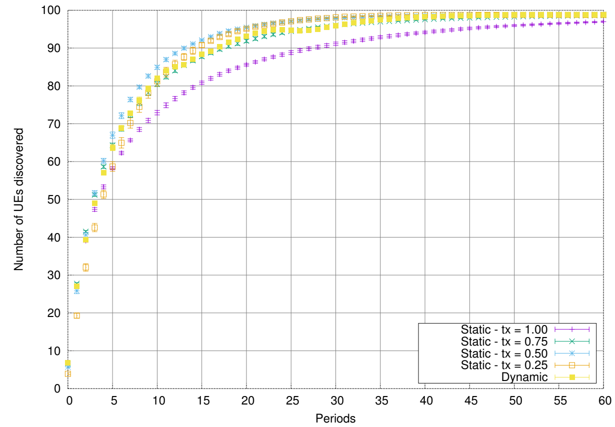
2) group 2 discovering everyone: We compute the number of periods needed to complete the discovery by group 2 in Fig. 4 with 95 % confidence intervals. The enhanced algorithm outperforms the 3GPP algorithm. The UEs in the second group finish discovery (including the first group) later than the first group, because they are simultaneously discovering UEs from the first group and their own group. We notice that, for both algorithms, the number periods needed to finish the discovery for group 2 is inversely proportional to the number of UEs in the first group, as fewer UEs in group 2 means fewer UEs to discover the whole group, thus saving time.

B. Departure Scenario

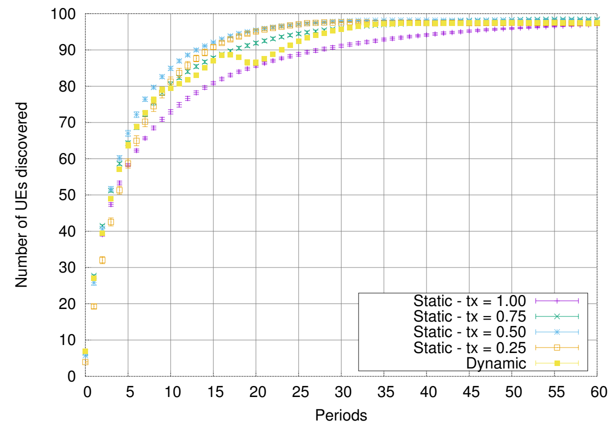
This second scenario will serve to analyze and validate our algorithms in scenarios with UEs departing the group. We assume that we have a group with 100 UEs. Y (with $0 \leq Y < 100$) UEs start leaving the group after 100 seconds. This value was chosen to allow the UEs to have enough time to complete the discovery. We implemented the departure detection logic as described in Algorithm 1 and Algorithm 2. We first focus on the beginning when the 100 initial UEs start discovering each other. Then, we evaluate the departure process and how UEs react to the changes in the group. We also vary the success criteria (99 %, 95 %, and 90 %) and assess how that affects the number of UEs discovered and the estimate reliability. We also studied 85 %, 80 %, and 75 % success criteria, with the overall trend for their performance being similar to the results presented. However, these results have not been included due to space limitations. From this point onward, the 3GPP results will be about the modified 3GPP, unless explicitly stated otherwise.

1) The discovery process at the beginning: We evaluate the discovery process at the beginning of the simulation, when all UEs are in the group. The results for different success criteria values are represented in Fig. 5.

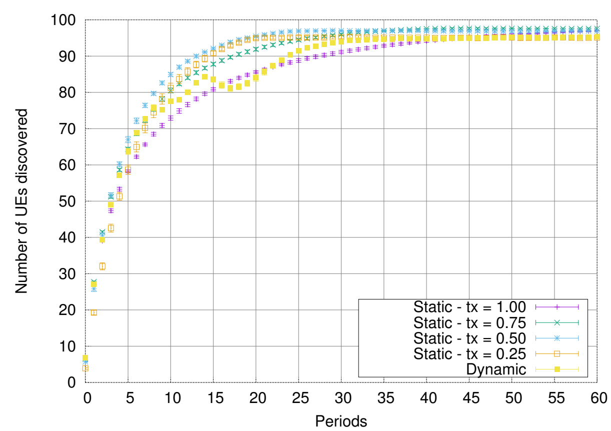
In the 3GPP case (i.e static), starting with $\theta = 1$ makes the discovery take the most time. For values of 0.25 and 0.5, the performance is close and the best. The enhanced algorithm, although less efficient than starting with the optimal transmission probability, succeeds to catch up with that ideal case, with minimal overhead.



(a) Success criteria = 99 %



(b) Success criteria = 95 %



(c) Success criteria = 90 %

Fig. 5: Number of periods needed for all UEs to discover all other UEs in the group for different success criteria values

Varying the success criteria value affects the discovery process in different ways. For the enhanced algorithm (i.e. dynamic), the algorithm oscillates at some points of the simulation, as it assumes that some UEs left the group after not hearing from them for a while, due to the fact that most UEs are changing their transmission probabilities simultaneously. This is more obvious for values of the success criteria lower than 99 %. The number of UEs is increasing and the optimal transmission probability is switching from 1 to 0.25. UEs are tuned to wait less according to Eq. 6. When they don't hear from other UEs after the time period they originally computed, they consider them gone and the mean estimated group size decreases.

For low success criteria values, we have an unreliable judgment which impacts the accuracy of the computed wait time. However, those UEs may have changed their own θ values to accommodate the UEs discovered and thus they are announcing less frequently. Once this new information is propagated, the actual number of UEs discovered increases back to what it is expected. We don't observe those oscillations for the 3GPP algorithm because it uses a constant transmission probability (Eq. 3).

For both the enhanced and the 3GPP algorithms we see that, with success criteria lower than 99 %, it is not possible to acknowledge the total number of UEs in the discovery group, with the difference between the "discovered" amount of UEs and the total increasing as the success criteria decreases. This inaccuracy is due to the fact that some UEs do not wait long enough before assuming another UE has departed the group.

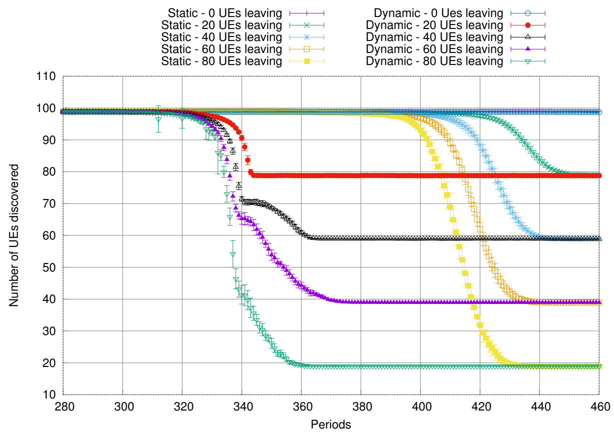
2) *The discovery process after 100 seconds:* At this time, some UEs leave the group (for simulation purposes, this happens instantly). First, we evaluate the effect of the change of the initial value of θ. Then, we study the impact of different success criteria values on both algorithms. In the following figures, in order to improve clarity of the plots, we have zoomed in at the time at which UEs started leaving the discovery group (i.e. around 300 discovery periods). In Fig. 6, we consider a 3GPP transmission probability of 1 and we vary the success criteria. In this case, the 3GPP algorithm is using $\theta = 1$. Based on Eq. 3 and Eq. 6, the probability of success is low and the UEs wait longer before deciding to discard other UEs from the discovery group because of the potential collisions and the half-duplex feature. The wait time is longer when the accuracy required is high.

For the enhanced algorithm, the departure process starts at $\theta = 0.25$. We notice a stair effect generated by the change of the transmission probability based on the number of UEs discovered over time, which affects the pace of the discovery process as well. The concavity is smoother as the success criteria is smaller.

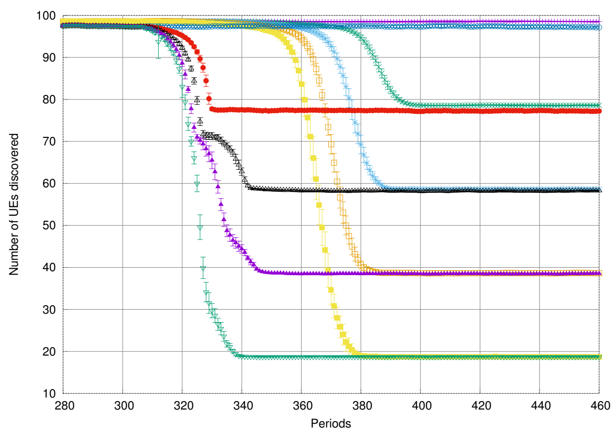
Like the 3GPP algorithm, the enhanced algorithm drops UEs faster and the wait time is reduced for low success criteria values. However, the impact of the success criteria on the reduction of the wait time is more perceptible for the 3GPP algorithm than for the enhanced algorithm.

We also notice how, even though lower success criteria reduces the time required to assume that UEs have left the group, this also makes the algorithms to miscount some UEs as departed, thus reducing estimated total group size. The gap between the computed number of UEs leaving and the "expected" group size gets wider for lower success criteria.

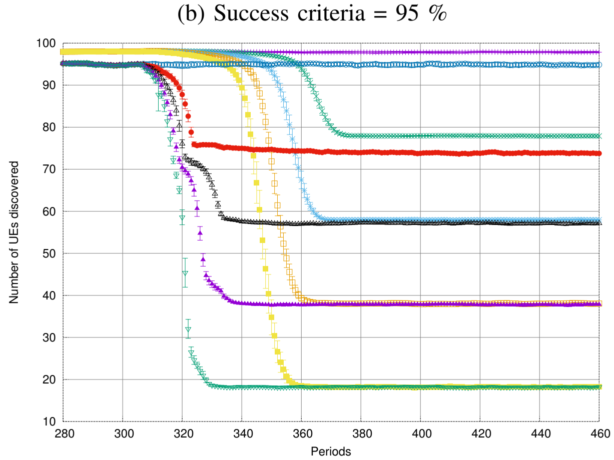
Similar conclusions can be drawn when considering initial transmission probabilities of 0.75, 0.5, and 0.25, with a narrower gap between the performance of both the enhanced and the 3GPP algorithms.



(a) Success criteria = 99 %



(b) Success criteria = 95 %



(c) Success criteria = 90 %

Fig. 6: Number of UEs acknowledged to be in the group over time for different success criteria values (3GPP transmission probability = 1)

In Fig. 7, we fix the success criteria to 99 % while varying the initial transmission probability. The discovery performance and the number of UEs left does not change in the enhanced algorithm case. At that point, the UEs transmit using the optimal θ (i.e. 0.25), and the initial θ value doesn't affect its behavior. The change occurs for the 3GPP case. We notice that it takes less time to start considering some UEs gone. For example, the system reaches a stable state after 330 periods for an initial transmission probability of 0.25, compared to 460 periods for an initial transmission probability of 1. That is when the 3GPP algorithm behaves the worst. The performance penalty is represented as the longer time required to learn that UEs left the group,

For $\theta = 1$ initially, the enhanced algorithm outperforms the 3GPP algorithm and succeeds to reach a stable state faster. For $\theta = 0.75$ initially, the enhanced algorithm reaches a stable state at approximately the same time as the 3GPP algorithm, although the enhanced algorithm drops more UEs over time. Less congestion and contention are recorded, which delays the convergence to the actual number of UEs in the discovery group.

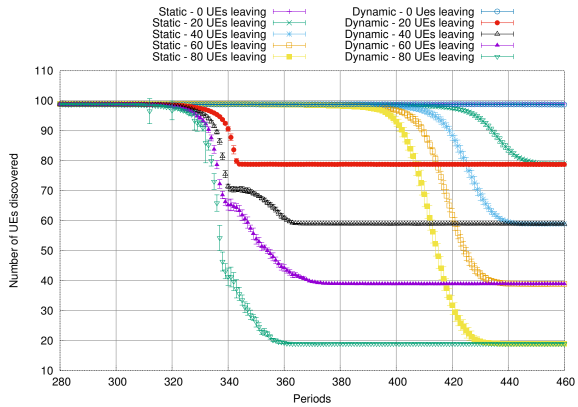
For $\theta = 0.5$ initially, the discovery performance is close to the optimal case. The enhanced algorithm starts detecting more UEs leaving the discovery group at the beginning of the process. But, the 3GPP algorithm succeeds to catch up and reaches a stable state faster.

For $\theta = 0.25$ initially, the 3GPP and the enhanced algorithms have the same start point. This is shown through the graphs for the first 20 periods after the actual UEs departure (i.e. 306 periods). However, the 3GPP algorithm drops the number of UEs discovered faster than the enhanced algorithm, because UEs in the enhanced algorithm take time adjusting θ based on the number of UEs.

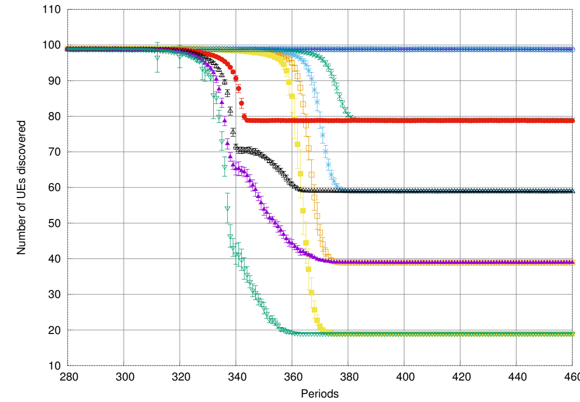
Although the 3GPP algorithm behaves better than the enhanced algorithm with $\theta = 0.25$, we showed in the previous paper [9] that a low transmission probability with small groups may increase the time required for discovery significantly, making it 3 times longer than needed. That is the strength of the enhanced algorithm: while fixed values of the transmission probability may provide better results for specific group sizes, that knowledge of the group size and channel conditions is generally known a priori, and in that case, the enhanced algorithm consistently provides near-optimal and very consistent results for groups of any size, regardless of UE arrivals and departures.

V. Conclusion and Future Work

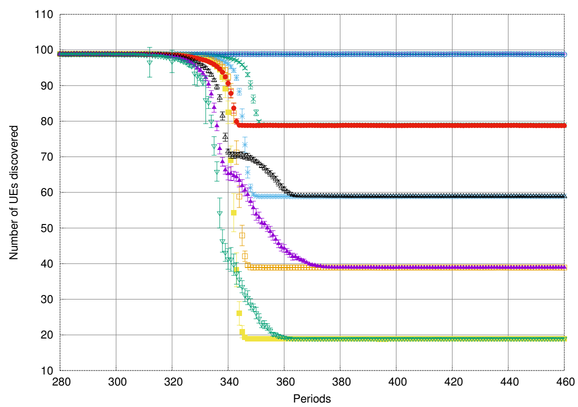
In this paper we presented an enhanced discovery algorithm for LTE D2D to be used in out-of-coverage scenarios. The enhanced algorithm builds on previous proposals that identified the optimal transmission probability depending on the group size, and extends them enabling the discovery process to fully be aware and react to dynamic changes in the network. We have shown how the algorithm can be tuned depending on whether the primary concern is fast adaptation or accuracy, making the process more suitable to be used in a wide variety of scenarios. From this contribution we can foresee several research possibilities, such as the automation of the tuning parameters depending on the group size volatility.



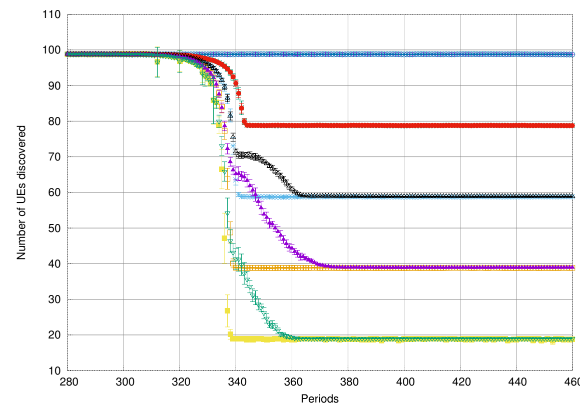
(a) 3GPP transmission probability = 1



(b) 3GPP transmission probability = 0.75



(c) 3GPP transmission probability = 0.5



(d) 3GPP transmission probability = 0.25

Fig. 7: Number of UEs acknowledged to be in the group over time for different initial transmission probabilities and a success criteria of 99 %

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