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Firefly inspired Improved Distributed Proximity Algorithm for D2D Communication

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***Abstract*—Device-to-Device (i.e. D2D) communication underlaying cellular technology not only increases system capacity but also utilizes the advantage of physical proximity of communicating devices to support services like proximity services, offload traffic from Base Station (i.e. BS) etc. But proximity discovery and synchronization among devices efficiently poses new research challenges for cellular networks. Inspired by the synchronization behaviour of firefly found in nature, the reported algorithms based on bio-inspired firefly heuristics for synchronization among devices as well as service interest among them having drawback of large convergence time and large message exchanges. Therefore, we propose an improved O(n log n) distributed firefly algorithm for D2D large scale networks using tree based topological mechanism using RSSI based ranging scheme.**

***Keywords*-Long Term Evaluation-Advanced (LTE-A); Cellular networks, D2D (Device-to-Device); 3GPP (3rd Generation Partnership project); RACH (Random Access Channel);**

I. Introduction

In the recent years D2D communication is one of the most emerging technology for next generation cellular networks. D2D communication gives better resource utilization, higher data transmission in networks. The Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) has introduced D2D application in many scenarios which requires direct access with and without infrastructure. In infrastructure based D2D communication, initiation of D2D communication is manage by BS. Whereas without assistance from BS, UE searches its neighbor and transmits data in the proximity in self-organized manner.

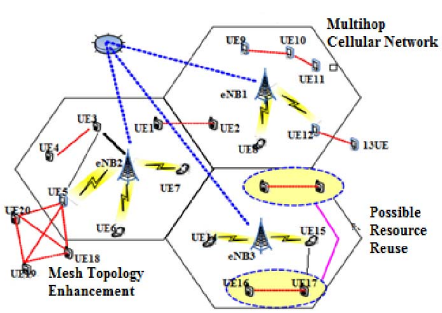

Figure 1. Device-to-Device communications underlay to a cellular networks.

Two devices will communicate with each other if their proximity criteria fulfilled. The main required criteria of proximity is geographical distance between devices. Proximity Service (i.e. ProSe) is defined in proximity context and it is an important feature of D2D communications. ProSe consist of device discovery and communication among them in close physical context. The proximity discovery can be categorized in two context such as physical communication and application discovery [1]. In physical level proximity discovery signal exchange among devices whereas in application level discovery a device search another device with same interest in the network. To make communication among devices robust and efficient, there is need to combine the physical communication and application discovery. Fig. 1. depicts a D2D communication among devices. For instance UE16 and UE17 can communicate each other because they are in proximity of each other.

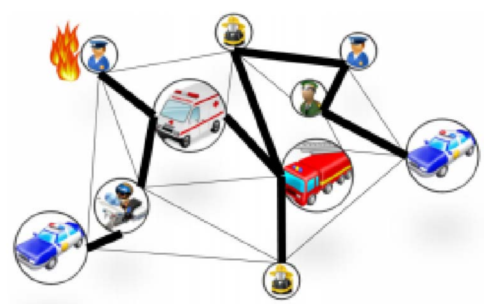

Figure 2. An instance of basic firefly spanning tree.

As per basic firefly algorithm, calculated distance may vary due to channel fading as well as the total control message overhead for synchronization among devices may go very high in whole network. So, to reduce above constraint, we model basic firefly algorithm with RSSI (i.e. receive signal strength indicator) model, which gives the exact expected error that may occur due to channel fading scenarios. Moreover, to reduce total message flow in network, instead of considering whole graph for each node, we create sub tree to reduce control message overhead in network. A typical example of firefly spanning tree shown in Fig. 2. It is shown that by selecting heavy edge, devices make synchronization in networks. From the numerical results

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obtained from our proposed model, it shown that our method give better convergence time with less number of control message overhead in networks comparing existing work [17].

Rest of this paper is organized as follows. Section 2 summarises related work, neighbour discovery in D2D cellular networks. Section 3 discuss about the basic firefly synchronization model. Section 4 presents proposed neighbour discovery and synchronization algorithm. Section 5 presents numerical results. Finally, Section 6 concludes this paper.

II. Related Work

D2D discovery can be perform in two way, either it perform by UE (i.e. User Equipment) by transmitting discovery beacons signal or, if for a particular time interval no beacon is transmitted then device discovery will be done by assistance of eNB (i.e evolved Node-B) or core network. In [2], an eNB determine the device discovery by checking location of devices or comparing packet transmitted from two devices. Authors [3] proposed, packet data network (i.e. P-GW) determine either UEs belong to same cell or other cell by detecting routing-back IP packet. In [4],[5],[6],[7], a power saving technique applied in which device transmits beacon signal randomly which makes a feasible trade-off between power conservation and device discovery. Authors[8],[9] considered the duty cycles of power saving devices as well as designed, so that a particular device discover other device in network. Authors [10],[11],[12] proposed a distributed reservation based protocol i.e. FlashLinQ. All devices transmit their identity message on an peer discovery resource ID (i.e. PDRID) in particular period.

In [13], Wener-Allen et al. implemented decentralized Reachback Firey Algorithm (i.e. RFA) on TinyOS-based motes and provided theoretical improved result. Authors [14] proposed Meshed Emergent Firefly Synchronization (i.e. MEMFIS) which multiplexes synchronization word with data packet and adopt local clock upon reception of synchronizing nodes. In [15], authors applied firefly model for synchronizing ad hoc networks. Authors [16] discussed about the general model of synchronization and convergent condition of nodes in network. Authors [17] applied firefly model in D2D communication for LTE-A networks. They have proposed distributed algorithm for neighbor discovery and service discovery simultaneously. In this work authors mainly focused on device synchronization issues. They did not consider, how the signal strength will vary from distance aspect when noise or real environment come in picture. In [18], authors applied firefly algorithm. They have considered the characteristics pulse of Ultra Wide Band (i.e. UWB) to ensure synchronization procedure of pulse coupled oscillator.

III. Firefly synchronization model

In D2D communication the main challenging task is synchronization among the devices. How to check the proximity condition among devices? To solve above mentioned problems we model D2D proximity and synchronization with basic firefly algorithm. In this model we consider, for each firefly there is a particular oscillator which shows the internal clock addressing when to flash and how to adjust it when receive pulse from other oscillators. So, the phase of oscillator changes when flash is emitted or received from other oscillators. These oscillator is termed as relaxation oscillator and presented by a series of pulses. This type of oscillator can be model with integrate-and-fire oscillators as mentioned in [19]. Integrate-and-fire oscillator interact with distinct events each time they attain an oscillation. Interaction takes in form of fires or pulse received from neighboring nodes.

Let us consider there are N number of oscillator exist. Let, the state of a particular oscillator i is presented such as x_i and its behavior is same as voltage as behavior in a RC-circuit, whereas its interaction can be describe as equation given below [20].

$$\frac{\mathrm{dx_i(t)}}{\mathrm{dt}} = -x_i + I_0 + \sum_{j=1, j\neq i}^{N} M_{i,j}.P_j(t) \tag{1}$$

Where I_0 control the period of uncoupled oscillator and $M_{i,j}$ determine coupling strength between oscillators. $P_j(t)$ defines as interaction between oscillators, is given by following equation number (2)

$$P_j(t) = \sum_m \delta(t - \tau_j^{[m]}) \tag{2}$$

Where $\delta(t)$ is known as dirac delta function and $\tau_j^{[m]}$ is m^{th} firing time of oscillator j.

As given in [20], equation (1) is unsolvable in close form of arbitrary N. So, each oscillator represented by phase function θ_i, which linearly incremented from zero to θ_{th}. where θ_{th} is phase threshold. Oscillators periodically fire every T seconds. So, equation (1) can be represented as following equation number (3).

$$\frac{\mathrm{d}\theta_i(t)}{\mathrm{dt}} = \frac{\theta_{th}}{T} \tag{3}$$

When $\theta_i(t) = \theta_{th}$ a node resent its phase to zero. If a oscillator not coupled with any oscillator then it naturally fires with a period equal to T. Let us consider a node j $(1 \leq j \leq N)$ fires at instance $t = \tau_j$, i.e. $\theta_j(\tau_j) = \theta_{th}$, all the nodes adjust their phase as following:

$$\begin{cases} \theta_j(\tau_j) = 0 \\ \theta_i(\tau_j) = \theta_i(\tau_j) + \Delta\theta(\theta_i(\tau_j)) \; for \; i \neq j \end{cases} \tag{4}$$

Phase increment $\Delta\theta$ can be determine by Phase Response Curve (i.e. PRC). Mirrollo and Strogatz [19] have given mathematical demonstration as $x_i(t) = f(\theta_i(t))$ is concave up and return map as $\theta_i(t) + \Delta\theta(\theta_i(t)) = g(x_i(t) + \varepsilon)$, here ε epresents amplitude increment. Further resulting operation written as $\theta_i(t) + \Delta\theta(\theta_i(t)) = g(f(\theta_i(t)))$, and this represents PRC, further piecewise linear function written as $\theta_i(t) + \Delta\theta(\theta_i(t)) = min(\alpha.\theta_i(\tau_j) + \beta, 1)$ with

$$\begin{cases} \alpha = e^{a.\varepsilon} \\ \beta = \frac{e^{a.\varepsilon}-1}{e^{a}-1} \end{cases} \quad (5)$$

Here, a is a dissipation factor. α and β determine coupling between oscillator. The threshold value θ_{th} normalized to 1. As It is given in [19], that if a network is fully meshed along with $\alpha > 1$ and $\beta > 0$ $(\alpha > 0, \varepsilon > 0)$, then system always converges i.e. all oscillator will fire at a time.

Let us consider there are n fireflies $D_1, D_2....D_n$, in a particular plane with coordinate $(x_i, y_i), i = 1, 2....n$. A firefly transmits PS (i.e. Proximity Signal) without knowing the current location of other firefly. Based on this PS, a firefly gets to know the actual distance from other fireflies. To estimate the distance among firefly we have used RSSI [21] model. In this model a firefly broadcast PS, on the basis of intensity of PS a firefly gets to know actual distance between them. Let D_i and D_j be a firefly located at (x_i, y_i) and (x_j, y_j) respectively. Let us assume D_i reads a distance r_i^* , whereas r_i is actual distance. So, relative error can be written such as following equation (6).

$$\epsilon_i = \frac{r_i^*}{r_i} - 1 \ \in [-1, +\infty] \quad (6)$$

The receive power from firefly i can be written as given below:

$$p^{**} = p^* + 10nlog(\frac{r_i}{r_0}) \quad (7)$$

Where p^* (dBm) is received at reference distance r_0, n is the path loss exponent its value depend on transmission medium such as for indoor 2 and 4 for outdoor. In our model we considered outdoor scenario. If received power at point l is p_l mW whereas at reference point $l^{'}$ is $p_{l'}$ mW, then receive power in dBm is written as following equation (8).

$$p_l = 10log(\frac{p_l}{p_{l'}}) \quad (8)$$

Actual power will differ from equation (7) to following equation (9) due to channel fading.

$$p^{***} = p^{**} + x \quad (9)$$

Here, x is a random variable which presents medium scale channel fading modelled as Gaussian zero mean with variance σ_2 in dBm. Now, equation (7) can be written as following:

$$p^{***} = p^* + 10nlog(\frac{r_i^u}{r^0}) \quad (10)$$

So, we can write the relationship between measure distance and actual distance as following.

$$r_i^u = r_i 10^{\frac{x}{10n}} \quad (11)$$

$$\epsilon_i = 10^{\frac{x}{10n}} - 1 \quad (12)$$

After going through above mathematical model of integrate-and-fire oscillator and RSSI, we can conclude that basic firefly algorithm can be apply for D2D communication. In this work we have proposed a distributed mechanism with RSSI model which enables neighbour discovery as well as service discovery simultaneously. This mechanism achieve synchronization among devices by detecting proximity signals (i.e. PSs) strength based on RSSI model. Each device sends PSs periodically. Every time after sending or detecting PSs from neighbouring node the counter value of devices increase by a fix rate. As counter value reach to threshold, the device sends PS and reset its counter to zero. This process will continue until all devices synchronized. In our network LTE-A, RACH (i.e. Random Access Channel) codec can be used for PS transmission. Different codecs scheme indicate different services in the application. Inspired by this technique we have considered that PS will use two different RACH codec i.e. a pair of RACH codec. One codec use for keep-alive i.e. for synchronization purpose where as other codec for other event. Since, LTE-A follow OFDMA (i.e. Orthogonal Frequency Division Multiple Access) for downlink. So, different RACH preambles can flow in network simultaneously without any interference. There might be intra-group proximity signal interference due to misalignment of devices. As per firefly algorithm property, this condition even hold.

IV. Proposed Neighbour Discovery and Synchronization Algorithm

We have modelled D2D communication with graph $G(V, E)$. Here, vertices V represent different devices in the network whereas edges E are communication links among them. We have given weight to links on the basis of PS strength. If PS strength is high then its respective weight will also be high. In other word we can say that the weight of edge is directly proportional to PS strength observed by nodes.

In our model we are following tree structure based topology. The main purpose of following tree structure is, to reduce total control overhead in network. Moreover, synchronization of nodes is always achieve with tree structure as proved in [17] . Keeping in mind, GHS and Boruvkas algorithm, we proposed distributed firefly algorithm to solve the problem using RSSI model. In this model we consider two RACH codecs. $RACH_2$ is use for synchronization among sub trees whereas $RACH_1$ for regular operation for firefly algorithm. Pseudo code of spanning tree is described in algorithm 1, 2 and 3. Each edge of trees are associated with particular weight based on PS strength. In beginning nodes know only weight of links to whom they are connected.

As per basic firefly algorithm assumption we considered (I) all devices are same type, (II) attractiveness among

Algorithm 1: Spanning Tree (V, E)

```
1  for each vertices v in graph G do
2      S_v ⟵ Generate a Spanning_Tree(v)
3  ST ⟵ {S_v | v ε V}
4  /* for each S_v perform following step 5 and 6 in parrallel */
5  F_F_A(S_v, S_{u≠v}, RACH_1); /* call algorithm 3 */
6  while |ST| ≠ 1 do
7      if H_Connect(S_{v.head}, S_v, ST) = true then
8          /* Call algorithm 2. */ do
           F_F_A(S_v, S_{u≠v}, RACH_2); /* call algorithm 3 */
9      else
10         Change_head(S_v)
11         continue;
12     /* Merge_Sub_Tree (S_v, S_u, ST) choose S_{v.head}
       from highest number of node's tree
       S_v ⟵ S_v + S_u */
13 Return ST;
14 End
```

Algorithm 2: H_Connect (v, Sv, ST)

```
1  if vertex v has no adjacent vertex u ∉ Sv then
2      Return false
3  while true perform following steps do
4      /* (u, v) is highest weighted edge ∉ Sv adjacent to v */
5      while ∅_v ≠ 1 do
6          if receive RACH_2 from u then
7              Broadcast RACH_2
8              Return true;
9          if receive RACH_2 from u then
10             Return true;
11         else
12             Return false;
13     Broadcast RACH_2
14     if receive RACH_2 from u then
15         Return true;
16     else
17         Return false;
18 End
```

devices are dependent on their brightness, (III) if all devices have same brightness then they move in random order. The dimension d is dependent on context of devices. The location update between two nodes (devices) i and j is given by following equation (13)

$$x_i = x_i + k.exp[-\gamma r_{ij}^2](x_j - x_i) + \eta\mu \qquad (13)$$

Where, η is parameter which control step size, μ is vector which drawn from Gaussian distribution. γ is attraction coefficient, k step size toward better solution and x_i is location information of device D_i. The exact calculated distance value will obtained by PS strength on the basis of RSSI model using equation (11), (12) and (13), which we have modelled in numerical analysis part.

V. Numerical Results

After running algorithms 1, 2 and 3, every node gets to know which of its link belong to spanning tree along with that they synchronize with rest of neighboring nodes. The resultant weight of our spanning tree will always be greater than weight of any spanning tree generated by same number of nodes.

It can be seen from equation (13), the basic algorithm of firefly is having inherent $O(n^2)$ time complexity. Because, in this case each firefly x_i must estimate equation (13) $O(n)$ times, for rest of fireflies x_j , $1 \leq j \leq n$ and $j \neq i$ [22]. Our distributed algorithm differ from this basic algorithm, maintaining an ordered tree structure of fireflies. Inner loop is use for ranking the brightness among fireflies

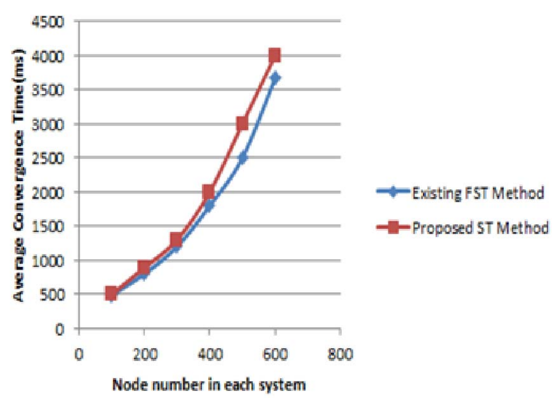

Figure 3. Comparison in convergence time between existing FST method with proposed ST method at different scales.

using sorting algorithm [23]. So, searching in firefly for more brightness than current firefly will take $O(log\ n)$ time complexity because of ordered tree structure of fireflies. Hence asymptotic time complexity of proposed distributed algorithms are $O(n\ log\ n)$.

In our simulation part we have considered outdoor non-line-of-sight model as mentioned in [24], under 100m*100m areas. Referencing to work [24] and [25], we have measured our results. Simulation parameters used in result measurement are given in Table1. Each device power of is considered 23 dBm, threshold value is -95dBm, whereas total number of devices in system are 50. Channel model is Non line

Algorithm 3: F_F_A $(Sv, Su \neq v, RACH)$

Generate initial population of firefly D_i with location x_i Where $i = 1, 2, 3, ...n$ number of firefly
Define objective function $f(x)$, where $x = (x_1 x_2 x_d)^T$
Evaluate light intensity (i.e. I_i) of each fireflies (i.e. $RACH$ of devices) light intensity I_i of a firefly D_i is determine by $f(x_i)$ */
Define light absorption coefficient Υ
Sort each firefly according to light strength
while $\Phi_v \neq 1$ **do**
  for $i \leftarrow 1$ ***to*** n **do**
    for $j \leftarrow 1$ ***to*** n **do**
      if $I_i > I_j$ **then**
        Move D_j toward D_i in d dimension
      Attractiveness varies with distance r as $exp[-\Upsilon r]$
      Evaluate new solution and update light intensity
  Rank the fireflies and find the current best
Return
End

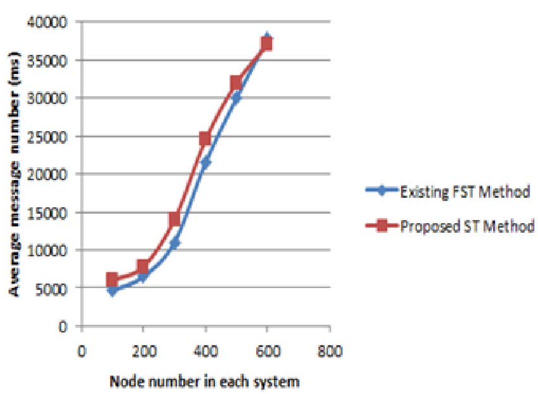

Figure 4. Comparison in average number exchange between existing FST method with proposed ST method at different scales.

of Site, time slot is 1 ms as per LTE standard. In our model we considered shadowing standard deviation as 10 dB. Propagation model varies on the basis of distance, measured in dB. Further, we have compared our result with the work done in [17].

Fig. 3. presents a comparison between proposed ST method with existing work FST [17] method. From the result we can conclude that when the number of node in the system is below 200, the existing FST method and proposed ST method perform with almost same rate. As the number of nodes are increasing in the system, our proposed ST method perform better way than existing FST method.

Another result as shown in Fig. 4. depicts message exchange during converging process. As the number of nodes are increasing in system, the total number of exchange messages is also increasing in proposed ST method as well as in existing FST method. When number of nodes in system are around to 600, the total number of messages exchange in proposed ST method is more efficient than existing FST method. We are getting better performance because, for large number of nodes our proposed algorithms give linear time complexity. Moreover, with the help of RSSI model a device gets efficient expected location of other device to move in right direction. So, by obtained results we conclude that our proposed ST method is more efficient in compare to existing FST method.

Parameters	Details
Device Power	23 dBm
Threshold	-95 dBm
Device Density	50 devices in 100 m*100 m areas
Fast Fading	UMi (NLOS)
Shadowing Standard Deviation	10 dB
Time Slot	1 ms
Propogation Model in dB	$PL = 4.35 + 25log_{10}(d)\ if\ ; d < 6$ $PL = 40.0 + 40log_{10}(d)\ ; otherwise$

Table I
SIMULATION PARAMETERS

VI. CONCLUSION AND FUTURE WORKS

In this work we have modelled distributed firefly algorithm for neighbour discovery and service discovery simultaneously, along with these services, this algorithm also achieves synchronization and same service interest among devices meanwhile. With the help of simulation analysis we conclude, this algorithm achieves an efficient convergence time comparing with existing literature for LTE-A D2D networks. In future, this proximity discovery concept can be extent to more realistic scenarios of D2D LTE-A networks, neighbour discovery and service discovery concept.

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