A Novel Multi-Hop Routing Protocol for D2D Communications in 5G

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***Abstract*—Device-to-Device (D2D) communication in 5G networks is designed to offload the traffic on the core networks and backhaul 回傳 links, and to provide faster and energy-efficient access to the devices within a cell. However, efficient provision of D2D communication presents several challenges, including multi-hop routing to the devices that are not immediate neighbours. Dynamic Source Routing (DSR) is a popular protocol commonly applied to Mobile Ad hoc Networks (MANET); however, its direct application in 5G environment is not straightforward. In this paper, a new multi-hop routing protocol for D2D communications in 5G network is proposed. The protocol modifies the conventional DSR protocol and takes advantages of 5G cellular infrastructure to make fast routing decisions. The proposed protocol offers low overhead over the conventional DSR, in terms of the number of control messages in the D2D communication, thus saving for the devices during route finding process. Simulation results show that the proposed protocol also achieves better results in terms of D2D routing success probability.**

☼DSR協定常用於MANET，本文修改DSR協定，利用5G基礎建設來做出更快的路由決定，也能降低成本。

***Index Terms*— D2D communications, 5G, Multi-hop Routing, Dynamic Source Routing (DSR)**

I. INTRODUCTION

In 5G networks, the device-to-device (D2D) communication allows users to exchange data directly in an ad hoc manner with no or very limited involvement 關聯 of the Base Station (BS). D2D communication has recently attracted a huge attention due its higher power efficiency, spectrum efficiency, and lower delays, among many others. One important advantage of D2D communication is in the caching strategies in 5G where contents 滿足 can be stored at the edge of the network, and the contents can be shared among several User Equipment (UEs) using D2D. This strategy of contents sharing also reduces traffic tremendously 非常的 on the core network and backhaul links.

☼D2D通訊需要高節能、高頻譜效率、低延遲等要求

☼D2D的快取策略可滿足邊緣網路的使用，因此許多UE會使用D2D，以減少核心網路的交通和回傳連結

Routing in D2D communicating devices presents some challenges due to the mobility, non-cooperativeness, disconnection, interference, and battery constraints of mobile devices. In case when a source UE needs to connect to non-neighboring destination UE, a multi-hop routing protocol is needed. Moreover, increased coverage can be achieved by achieved by using multi-hop D2D.

☼D2D routing 的挑戰：移動性、非協作性、未連線、干擾、行動裝置的電池限制

☼來源UE要連接非臨近的目標UE，多hop的協定是必須的

However, route finding and route maintenance offer several challenges in multi-hop D2D communication. Recently, several researchers [1-9] explored various multi-hop routing protocols with the objectives to maximize certain network performance metrics. However, most of the protocols reported are quite complex to implement in real practical networks. A good survey on the routing protocols in D2D environment is provided in [1]; however, this survey is geared more towards LTE.

☼現有的協定在真實網路中過於複雜而難以實行

Standards for two-hop communication has been already approved by 3GPP in Release 13-15. In order to access network services by a device that is out of network coverage, it can use another nearby device as a relay which is within network coverage, to communicate with the network [10]. Multi-hop D2D routing schemes can be divided into several classes, including incentive-based, security-based, content-based, location-based and flat topology-based routing [1]. The flat topology-based routing schemes can be subclassified based on the route discovery mechanism used, i.e., (a) reactive routing, and (b) proactive routing, and (c) hybrid routing, where both the reactive 反應的 and proactive routing operate at the same time. A social-tie based routing scheme is proposed in [11]. In this scheme, the route is determined by the BS, and the scheme assumes that the mobile users are connected with some sort of social ties and the network operators can extract the social ties among the users. An assisted routing algorithm in 5G is presented in [12] where the D2D communications are managed by the base stations.

This paper proposes a new multi-hop routing protocol designed to be used for D2D communication in 5G networks. The proposed protocol is an extension of a well-known routing protocol for ad hoc networks, the Dynamic Source Routing (DSR), but designed to take into consideration of D2D support in 5G architecture. The proposed protocol adds low overhead (in terms of control messages) as compared to the DSR, and it performs better than the classical DSR by achieving better routing packet delivery ratio, better network management and overall network throughput.

The rest of the paper is organized as follows. Section II presents a brief overview of the problem and describes briefly the working of the DSR. Section III describes the proposed multi-hop routing protocol and compares it with the conventional DSR, and section IV presents conclusions.

II. Multi-Hop Routing in D2D

A. Motivation

Designing a multi-hop routing protocol meeting several, often conflicting, performance objectives at the same time is quite challenging. The main ideas in the proposed multi-hop routing protocol are the followings:

- Minimal or no participation of Base Station (BS) in the route discovery process.
- Use of base station (or cellular 5G cellular infrastructure) in maintaining an up-to-date record about D2D sessions within a cell, and the routing information within a D2D session.
- A simple, low-overhead, strategy for route discovery and route maintenance, by modifying the conventional Dynamic Source Routing (DSR) to suit D2D communication in 5G.
- Minimizes the broadcast storm of RREQ packets in the network.

B. Conventional Dynamic Source Roting

The Dynamic Source Routing (DSR) is a popular routing protocol used in Mobile Ad hoc Networks (MANETs). DSR is a reactive (or "on-demand") protocol, and it does not require continuous information updates in order to build and maintain routes. During the route discovery phase, when a source node does not have the route information to a destination node, and it has data packets to be sent to the destination, then it broadcasts the Route Request (RREQ) packets to its immediate neighbors. Each intermediate node, upon receiving the RREQ, rebroadcasts the packet to its neighbors if it has not forwarded the packet already or if the node is not the destination node. Each RREQ packet carries a sequence number generated by the source node and every node appends its own node ID to the path information in the RREQ. The destination node, after receiving the first RREQ packet from a given source node, replies to the source node using the Route Reply (RREP) packet through the reverse path the RREQ packet had traversed. An intermediate node can also learn about the neighboring routes by any means, and caches this route information for potential future use and route optimization. In case of broken link (due to non-coverage, or other issues), the immediate affected nodes send Route Error (RRER) control packet along the route and all intermediate nodes update their caches to reflect the status of broken link in the path information.

☼DSR是一種反應型的協定，不需要資訊不斷更新，而是藉由廣播RREQ封包給鄰近節點

☼目標節點收到RREQ會回覆RREP封包，中間節點可以利用快取來存取鄰近的路由選擇，未來選擇路由的資訊、路由最佳化

III. The Proposed Protocol

The proposed multi-hop protocol for D2D communication has following main features different from the classical DSR.

- A node (also known as UE in 5G) has an up-to-date information about its immediate neighbor(s), if any. This information is periodically updated by sending "Hello"-type packets.

☼新協定會讓節點週期性更新路由資訊

- When a node X needs to find route to destination node Y, it first sends a probe message to its immediate neighbors. If unsuccessful to get routing information from its immediate neighbors, then X sends the request to the base station, as the base station might have an updated information for this requested route. If still unsuccessful in getting information from the base station, then the node X starts its route discovery process.

☼來源節點會傳送探查訊息給鄰近節點，若從鄰近節點得不到想要的資訊，就會從基地台要求資訊，或是進入發現路由的過程

- A node that is not willing to participate in the routing process (i.e., relaying data on the behalf of other nodes) can do by making itself "non-active" (or "invisible"). Therefore, a "non-active" node cannot be an intermediate relaying node; however, it can be a source or a destination node. There could be several reasons for such non-participation, including low battery power, security, or others.

☼一個未加入路由過程的節點是非主動的，而非主動的節點，只能當來源或目的節點，不可當中繼節點

- On receiving an RREQ packet, an "active" node X broadcasts the packet *only* when X is not the intended destination, or when one of the immediate neighbor of X is not the intended destination. Using this strategy, un-necessary broadcasts from node X are avoided, and hence the broadcast storm problem in the network is greatly controlled. As a large portion of a node's energy is spent on transmitting packets, therefore limiting unnecessary broadcasts will also definitely help in conserving the batteries at nodes.

☼當收到RREQ封包，只有主動節點會廣播封包，避免沒有必要的廣播而浪費資源，解決廣播風暴問題

- After getting successful route information, the source node caches the information in its local cache, and sends the information to the base station to be stored for future use.

☼節點成功得到路由資訊後，來源節點會將資料存於快取，並傳至基地台儲存

- The base station acts as a central "cache" for the most recent routing information within a D2D cluster present in the boundary of a cell.

☼基地台就像是中央快取

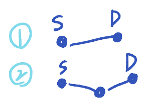
A. Protocol Description

The proposed multi-hop protocol introduces several modifications to the working of the basic DSR protocol to support efficient routing.

When a source node ("S") needs to send a data packet to a destination node ('D") and does not have a valid routing information, it initiates the route discovery phase. The following is the sequence of steps for the proposed protocol:

1. The source node, S, prepares a RREQ packet and includes its own address and the address of intended destination node, D, and broadcasts to all of its immediate neighbors. If the destination node, D, happens to be one of the immediate neighbor of the source node S or one of the neighbors of an immediate neighbor (i.e., second level neighbor of S), then destination node replies back with RREP (Route Reply Packet) along with the requested

☼來源節點準備RREQ封包，廣播給所有中間節點



routing information, and the route discovery phase ends.

☼無法從鄰近節點獲得路由資訊，就會發送要求到基地台，基地台發送RREP封包回覆

2. If unsuccessful in getting routing information from its immediate neighbors, then node S sends the request to the base station. If the base station has the updated routing information, then it replies back with an RREP packet containing routing information, and the route discovery phase ends.

☼基地台沒有路由資訊，則進入路由發現的過程，廣播RREQ封包

3. If no routing information is provided by the base station, then route discovery process similar to classical DSR starts. The source node, S, broadcasts the RREQ packet to its immediate neighbors.

☼X不是目標節點或X鄰近節點非目標節點時，X會廣播封包，每個廣播節點廣播前，都會在RREQ封包加上節點ID

4. On receiving the RREQ packet, an active node X broadcasts the packet *only* when X is not the destination, or when one of the immediate neighbors of X is not the intended destination. Each broadcasting node also appends its node ID to the REEQ packet before sending it.

☼目標節點收到RREQ封包時會傳送RREP給來源節點，中繼節點也會儲存路由資訊在快取

5. When the intended destination node, D, receives the RREQ packet, it does not broadcast further. The destination node prepares a Route Reply Packet (RREP), with the path information available to the source node S, and sends the RREP packet to node S. All the intermediate nodes relaying the RREP packet also cache the routing information for future use.

☼路由發現資訊會存在基地台的快取

6. The source node, S, relays the routing information gathered from the discovery process to the base station.

B. *Simulation Results*

A simulator program was written in C++ to simulate the working of the proposed protocol. The following simulation parameters were used:

- Terrain size: 2 km x 2 km; Area = 4 km^2
- Simulation time: 60 minutes
- Number of identical D2D nodes (UEs): 100
- UEs distribution: Random, outdoor
- Propagation Model: 3GPP Urban Micro (UMi)
- Mobility model: Random Waypoint (RWP)
- Speed of D2D nodes: 0 to 10 m/sec.
- MAC protocol among UEs on D2D: IEEE 802.11
- Routing request rate per UE: 2 requests per minute (towards a randomly chosen D2D node)
- Multi-path fading model: Rayleigh
- Shadow Fading Variance: 6 dBs
- Base Station Transmit Power: 40 W
- D2D UE transmit Power: 100 mW
- D2D UE Receiver Sensitivity: -100 dBm
- Data traffic type at UE : Constant Bit Rate (CBR) with data packets of size 512 bits were simulated to be sent from a source node to the destination node, at a regular interval of 5 sec.

The following performance metrics were studied through simulation:

- Average number of RREQ broadcast messages in the entire D2D network per routing request session.
- Average number of RREQ messages sent to the base station per routing request session.
- D2D Routing success probability.

C. *Comparison and Discussion*

The performance of the proposed protocol is compared with the conventional DSR protocol, and the results are shown in Figures 1 through 3.

Figure 1 shows the simulation results for the average number of RREQ messages generated in the D2D communication in response to a single request from a source node, as we increase the number of active UEs in the cell. The performance of the proposed protocol is at least 20% better than that of the conventional DSR. Less amount of broadcast traffic also translates directly into energy savings at the UEs.

Figure 2 shows the simulation results for the average number of RREQ messages sent to the Base Station (BS) in response to a single request from a source node, as we increase the number of nodes in the cell. It is clear from the figure that the number increases with the number of active nodes. More active nodes in the D2D communications results in sending route requests to distant nodes for which the routing information is not available at the immediate neighbors of the source nodes. Therefore, a RREQ request message is sent to the BS in the hope of finding the routing information to the destination.

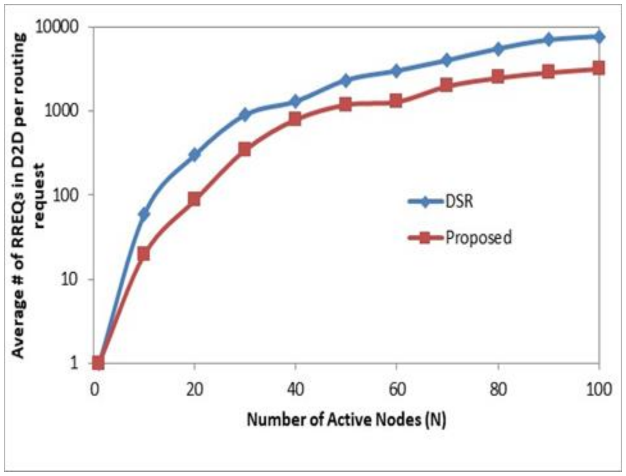


Figure 1: Simulation results for the average number of RREQ messages sent out in the D2D communication per routing request from a source node vs. number of active node present in the D2D communication for the conventional DSR and the proposed protocols.

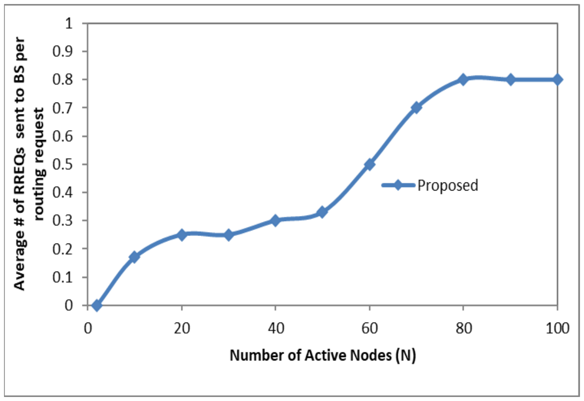


Figure 2: Simulation results for the average number of RREQ messages sent to the Base Station per routing request from a source node vs. number of active node present in the D2D communication for the proposed protocol.

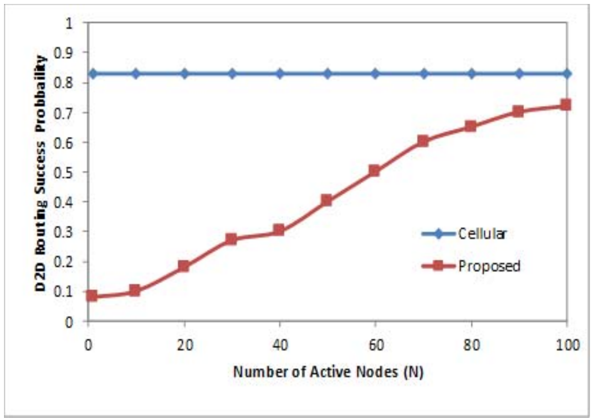


Figure 3: Simulation results for the D2D routing success probability vs. number of active node present in the D2D communication for the proposed protocol.

Figure 3 shows the simulation results for the probability that a D2D routing request results in eventual success, as a function of the number of active nodes. Again, more active nodes in a cell will result in higher success probability. Only a few nodes in the cell, most probably, will be located at far distances from each other, resulting in coverage and poor SINR (Signal-to-Interference+ Noise Ratio) issues; hence, resulting in lower success probability for the D2D connection.

IV. Conclusions

Design of a multi-hop routing protocol in D2D communication that provides both energy efficiency for the devices and fast route finding at the same time for 5G wireless networks is a challenging process.

This paper proposes a new multi-hop routing protocol that can be used in 5G networks. The protocol is simple to implement and extends the features from the standard DSR protocol. The protocol uses the base station to store the routing information. This storage can speed up the route discovery process in many cases. The protocol also allows UEs to save their power by limiting the broadcast storm in the network. Extensive simulations are done to evaluate the performance of the proposed protocol and a comparison with conventional DSR protocol is also made. It has been found that the proposed protocol can be easily implemented in 5G networks supporting D2D communications.

References

[1] F. S. Shaikh and R. Wismuller, " Routing in Multi-Hop Cellular Device-to-Device (D2D) Networks: A Survey", *IEEE Communications Surveys and Tutorials*, Vol. 20, No. 4, Fourth Quarter, 2018

[2] R.E. Ahmed, "A Fault-Tolerant Routing Protocol for Mobile Ad hoc Networks", *Journal of Advances in Information Technology (JAIT)*, Vol. 2, No. 2, May 2011, pp. 128-132.

[3] H. Yuan, W. Guo, and S. Wang, "Emergency Route Selection for D2D Cellular Communications During an Urban Terrorist Attack", 2014, http://arxiv.org/abs/1403.6923.

[4] Johnson, D. Maltz and Y. Hu. "The dynamic source routing protocol for mobile ad hoc networks", *IETF MANET Working Group, Internet Draft 2003*.

[5] H. Imai, H. Okada, T. Yamazato, and M. Katayama, "The effect of multipath hybrid routing protocol in multihop cellular networks," *IEEE 17th Int. Symp. Pers. Indoor Mobile Radio Commun. (PIMRC)*, Helsinki, Finland, 2006, pp. 1–5.

[6] C. Tata and M. Kadoch, "Multipath routing algorithm for device-to-device communications for public safety over LTE heterogeneous networks," *1st Int. Conf. Inf. Commun. Technol. Disaster Manag. (ICT-DM)*, 2014, pp. 1–7.

[7] G. Nardini, G. Stea, and A. Virdis, "A fast and reliable broadcast service for LTE-advanced exploiting multihop device-to-device transmissions," *Future Internet*, vol. 9, no. 4, p. 89, 2017.

[8] R. Alkurd, R. M. Shubair, and I. Abualhaol, "Survey on device-to-device communications: Challenges and design issues," *IEEE 12th Int. New Circuits Syst. Conf. (NEWCAS)*, Trois-Riviéres, QC, Canada, 2014, pp. 361–364.

[9] J. Liu, N. Kato, J. Ma, and N. Kadowaki, "Device-to-device communication in LTE-advanced networks: A survey," *IEEE Commun. Surveys Tutorials.*, vol. 17, no. 4, pp. 1923–1940, 4th Quarter, 2015.

[10] http://www.3gpp.org/release-15

[11] I. Koutsopoulos, E. Noutsi, and G. Iosifidis, "Dijkstra goes social: Social-graph-assisted routing in next generation wireless networks," in *Proc. 20th Eur. Wireless Conf.*, Barcelona, Spain, 2014, pp. 1–7.

[12] A. V. Bastos, C. M. Silva and D. C. da Silva, "Assisted routing algorithm for D2D communication in 5G wireless networks," IEEE 2018 Wireless Days (WD), Dubai, 2018, pp. 28-30, doi: 10.1109/WD.2018.8361688.