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 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.**

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 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 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 on the core network and backhaul links.

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. 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.

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 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.

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.
- 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.
- 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.
- 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.
- 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.
- 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.

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

routing information, and the route discovery phase ends.

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.

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.

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.

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.

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.

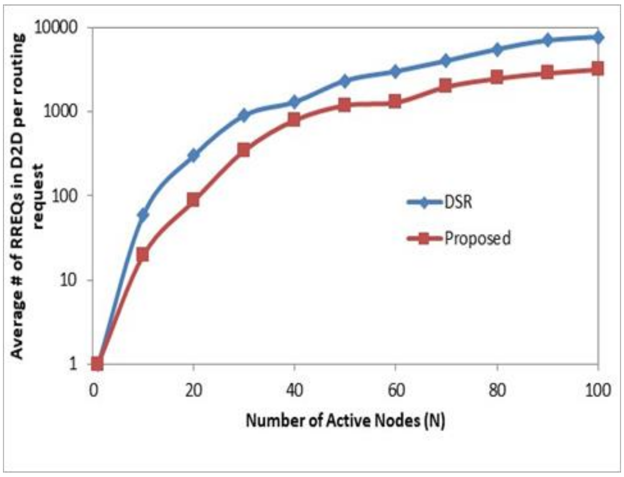

Figure 1: Simulation results for the average number of RREQ messages sent out in the D2D communication per routing request from a source node vs. number of active node present in the D2D communication for the conventional DSR and the proposed protocols.

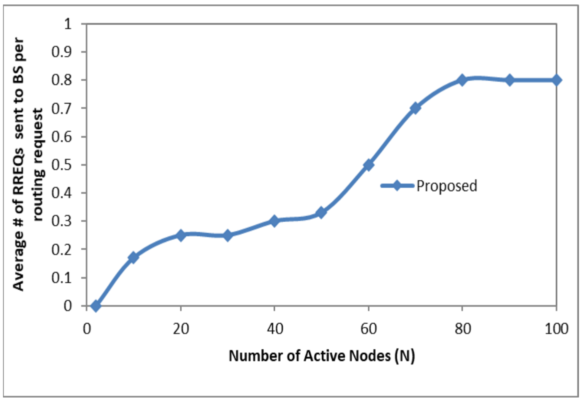

Figure 2: Simulation results for the average number of RREQ messages sent to the Base Station per routing request from a source node vs. number of active node present in the D2D communication for the proposed protocol.

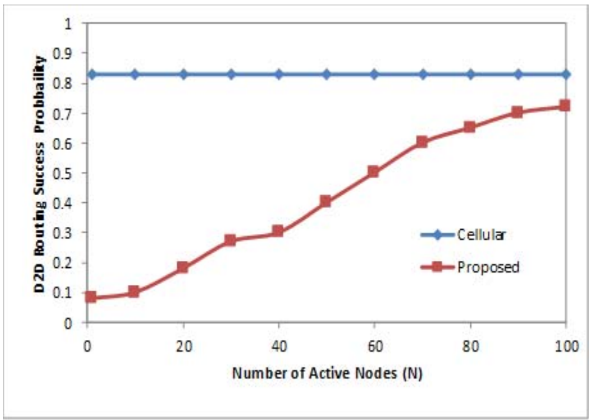

Figure 3: Simulation results for the D2D routing success probability vs. number of active node present in the D2D communication for the proposed protocol.

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.

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