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

Rana E. Ahmed
Dept. of Computer Science and Engineering, American University of Sharjah, United Arab Emirates
Email: rahmed@aus.edu

Abstract**—**Device-to-Device (D2D) communication is designed to offload the traffic on the 5G core networks and backhaul links in an effort to deal with the high volume and variety of data traffic anticipated in 5G networks. D2D communications 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 to each other. Dynamic Source Routing (DSR) is a popular protocol commonly applied to Mobile Ad hoc Networks (MANET); however, its direct application in 5G D2D 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 routing decisions faster. The proposed protocol offers low overhead over the conventional DSR, in terms of the number of control messages exchanged in the D2D communication, thus saving time and energy for the devices during the route discovery 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

Device-to-device (D2D) communication in 5G networks offers a new dimension in the mobile communications, easing the data exchange process among physically neighboring devices. D2D communication is designed to offload traffic on the core networks and backhaul links by effective utilization of available nearby resources, thus reducing latency and improving data rates. 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 (e.g., popular video clips) can be stored at the edge of the network, and the contents can be shared among several neighboring User Equipment (UEs) using D2D. This strategy of contents sharing also reduces traffic tremendously on the core network and backhaul links.

Routing among D2D communicating devices presents some challenges due to the mobility, non-cooperativeness, disconnection, interference, and battery constraints of mobile devices. When a source UE needs to connect to a direct-neighboring UE (i.e., single-hop communication), the communication can be established given the spectrum availability and acceptable signa-to-interference ratio, and no routing protocol is needed. However, in case when a source UE needs to connect to non-neighboring destination UE, a multi-hop routing protocol is needed, where the data will be forwarded by one or more intermediate devices. Moreover, increased coverage can be achieved by achieved by using multi-hop D2D routing. However, route finding and route maintenance procedures offer several challenges in multi-hop D2D communication. Single-hop communication results in several advantages such as reduced delay and increased energy efficiency [1]. Multi-hop routing/ relaying is, indeed, unavoidable when the devices involved in the communication are not in the coverage range of each other. The intermediate devices between a source and destination can be used as relays. In addition to increased coverage for D2D communicating devices, the multi-hop routing can help in devices to communicate more efficiently with the infrastructure network. Some other advantages gained by using multi-hop routing are better quality of service (QoS), higher user data rates, and better spectrum efficiency [1].

With the support of the D2D multi-hop communications, users can communicate with each other in one of the four possible ways: (i) single hop D2D communication (ii) multi-hop D2D communication (iii) multi-hop Device-to-Infrastructure (D2I)/Infrastructure to- Device (I2D) communication, and (iv) traditional cellular communication [1]. The term "infrastructure" here means the core network elements, such as a base station.

Recently, several researchers [1]-[10] 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 targeted more towards LTE networks.

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Fig. 1 shows a typical LTE/ 5G network with macrocell, picocell, and femtocell architecture. The D2D communication can initiated and controlled by the D2D devices under a complete or no control of the Base Station (BS).

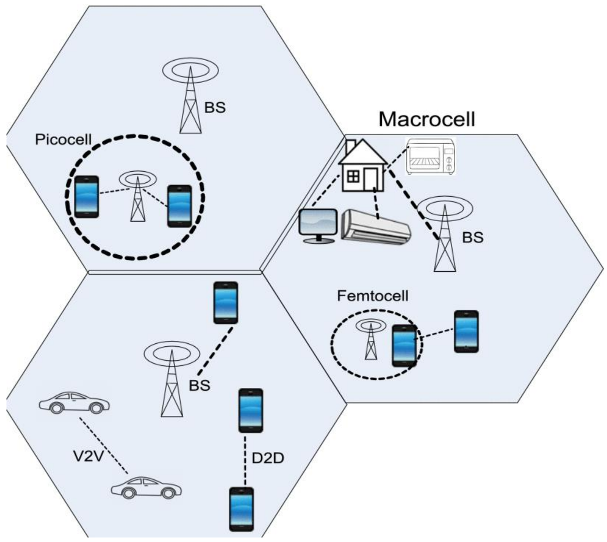

Fig. 1. A typical LTE/ 5G architecture supporting D2D communications.

Standards for two-hop communication has been already approved by 3GPP in Release 13-15 [11]. 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 [11]. 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 [12]. 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 [13] where the D2D communications are managed exclusively by the base stations. In order to motivate a user in assisting in multi-hop relaying process, some incentives (such as monetary or better future services) to the participating users have been suggested in [14]-[16]. A hop-based routing protocol ensuring confidentiality, authenticity and integrity is proposed in [17], where each mobile station uses symmetric cryptography and shared secret key with the neighboring mobile node.

This paper proposes a new low-overhead 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. It should be mentioned that the other MANET protocols (e.g., AODV, DSDV) can also be modified using similar concepts and strategies mentioned for DSR to design multi-hop routing protocols.

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*

For D2D communications, 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. This will ensure bare minimal use of network resources during route discovery process without overwhelming the BS.
- 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. The up-to-date route is the final outcome of the route discovery process and this information should be stored at some reliable and robust network entity, such as the BS.
- 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. Major features of DSR remain unchanged.
- Minimizes the broadcast storm of Route Request (RREQ) packets in the network. This will ensure efficient use of network resources during route discovery process.

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 ready 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 packet. 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 a 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 by a node to all its immediate neighboring nodes.
- When a node X needs to find route to destination node Y, it first sends a probe message to its immediate neighbors. If node X is 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.

Fig. 2 shows a typical scenario in D2D communication multi-hop routing. The relaying nodes (devices) are shown to be willing to participate in route finding process.

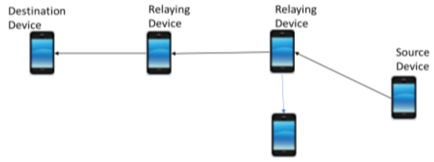

Fig. 2. An example scenario illustrating multi-hop routing.

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 node S is 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 already cached 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 (from RREQ packet), 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 for future use, and the route discovery process ends.
7. The routing information stored (cached) at the base station and the D2D communicating nodes is purged (i.e., deleted) after some known time-out interval (TO). This time-out-interval can be chosen to reflect the mobility characteristics of devices, expected duration of a D2D session and the wireless channel characteristics.

B. Simulation Results

A simulator program was written in C++ to simulate the working of the proposed protocol. Table I shows the simulation parameters used with their default values.

TABLE I: SIMULATION PARAMETERS

Parameter	Default Value
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 (stationary) 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.
Time-out Interval (TO)	3 minutes.

The following performance metrics were studied through simulation:

- **Average number of RREQ broadcast messages in the entire D2D network per routing request session.** This metric is calculated as the ratio of the total number of RREQ messages generated in the entire D2D network to the total number of route-finding sessions.
  A comparison of this metric for the proposed protocol with the conventional DSR tells us directly about the saving in terms of control messages sent out, and indirectly about the energy savings for the D2D devices. The metric also gives a qualitative idea about the network congestion and network resources utilization during routing process.
- **Average number of RREQ messages sent to the base station per routing request session.** This metric is calculated as the ratio of the total number of RREQ messages sent to the base station to the total number of route- finding sessions. This metric translates into the fraction of RREQ messages that could not find the route information from the source or its immediate neighbors; nevertheless, sending an RREQ message to the base station does not always guarantee the access to the desired route information.
- **D2D Routing success probability**. This metric indicates the fraction of the RREQ messages that end up in getting the desired route information either from D2D or the cellular network.
- **Data Packet Delivery Ratio.** This metric represents the ratio of the number of data packets successfully delivered to the destinations during data transfer session after finding a route to the destination to the total number of data packets sent out in the network. This metric provides an estimate of how well the protocol is behaving for delivering packets under different D2D network parameters (e.g., Time-out interval, distance between D2D devices).

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 4.

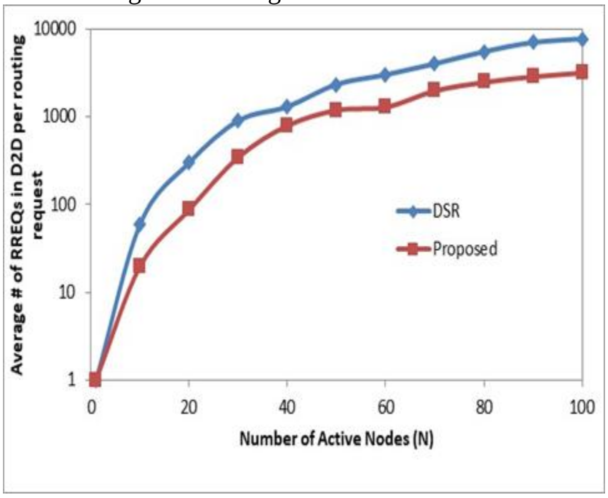

Fig. 3. Simulation results for the average number of RREQ messages sent out in the D2D communication per routing request from a source node vs. number of active nodes present in the D2D communication for the conventional DSR and the proposed protocols.

Fig. 3 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 and less network congestion.

Fig. 4 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 active 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.

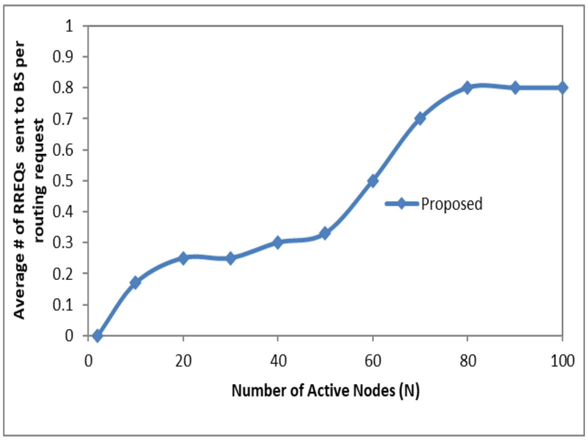

Fig. 4. Simulation results for the average number of RREQ messages sent to the Base Station per routing request from a source node vs. number of active nodes present in the D2D communication for the proposed protocol.

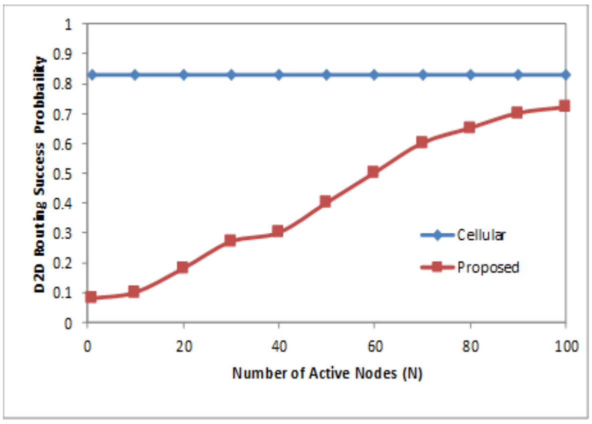

Fig. 5. Simulation results for the D2D routing success probability vs. number of active nodes present in the D2D communication for the proposed protocol.

Fig. 5 shows the simulation results for the probability that a D2D routing request results in eventual success of finding route, 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 poor coverage and poor SINR (Signal-to-Interference plus Noise Ratio) issues; hence, resulting in lower success probability for the D2D connection.

Fig. 6 shows the results for the data packet delivery ratio as a function of active nodes in the D2D network. This ratio gives us a clear idea how good or bad the routes are discovered in terms of their effectiveness in actual data packet transmission. When all nodes are stationary (i.e., at zero speed), and the D2D communication is only facilitated by the base station (i.e., in cellular mode), then the packet delivery ratio is almost constant and is independent of the number of active nodes. For nodes moving at light speeds (e.g., 1-5 m/sec), the D2D communications facilitated by the base station will change the packet delivery ratio only slightly. However, in the proposed protocol, only the routing decisions can be facilitated by the base station, while the actual data packets are still sent over the multi-hop D2D network using UEs. As the number of active nodes (UEs) in the given area is small, then most likely those UEs are located at large distances from each other, resulting in poor channel conditions and hence lower packet delivery ratios. However, as the number of active UEs increases, the UEs will have more nearer neighbors, and thus the data packet delivery ratio is better due to good channel conditions. The UEs moving at higher speeds experience poor channel conditions due mobility, thus there will be coverage issue especially when the number of UEs is small and they are located at far distances from each other. However, when the number of UEs increases, even with mobility, the UEs should be able to pair and find relay nodes (UEs) to find roue and transmit data packets.

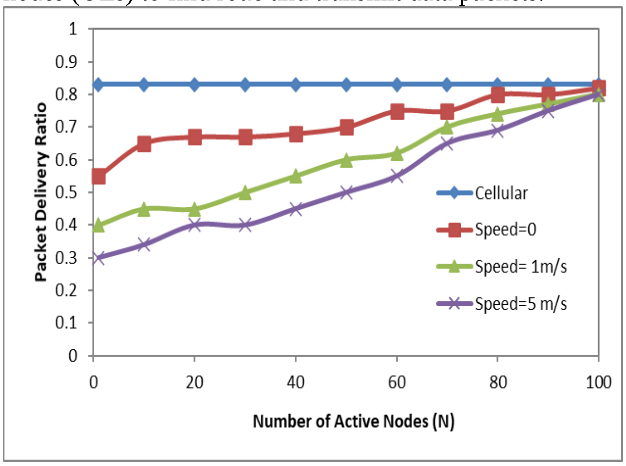

Fig. 6. Simulation results for the Packet Delivery Ratio vs. number of active nodes moving at different speeds for the proposed protocol.

It should be also noted that Time-out interval (TO) plays an important role in the route discovery process. On one hand, we like to make sure that the value of TO is not too large that we end up with outdated and stale route information stored at the caches of base station and the relay nodes. On the other hand, TO value should not be so small that we are forced to purge correct routing information prematurely. Assigning an optimal value for TO depends on the estimate of the duration for which the network and channels remain stable.

IV. Conclusions

Designing a multi-hop routing protocol in D2D communication that provides low overhead, in terms of 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 integrated easily 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 when the route information cannot be quickly be assembled from neighboring UEs. The protocol also allows UEs to save their energies 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 is concluded that the proposed protocol performs better as compared to the conventional DSR on many aspects. The protocol offers low overhead in terms of control messages sent to establish the route. It has been found that the proposed protocol can be easily implemented in LTE and 5G networks supporting D2D communications.

Conflict of Interest

The author declares no conflict of interest.

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. (2014). Emergency route selection for D2D cellular communications during an urban terrorist attack. [Online]. Available: http://arxiv.org/abs/1403.6923

[4] Johnson, D. Maltz, and Y. Hu, "The dynamic source routing protocol for mobile ad hoc networks," in *Proc. 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," in *Proc. 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," in *Proc. 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," in *Proc. IEEE 12th Int. New Circuits Syst. Conf. (NEWCAS)*, Trois-Rivières, 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] M. Abdollahi, M. Abolhasan, N. Shariati, J. Lipman, A. Jamalipour, and W. Ni, "A Routing Protocol for SDN-based Multi-hop D2D Communications," in *Proc. 16th IEEE Annual Consumer Communications & Networking Conference (CCNC)*, January 11-14 2019, Las Vegas, USA.

[11] 3GPP. [Online]. Available: http://www.3gpp.org/release-15

[12] 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.

[13] A. V. Bastos, C. M. Silva, and D. C. D. Silva, "Assisted routing algorithm for D2D communication in 5G wireless networks," in *Proc. IEEE 2018 Wireless Days (WD)*, Dubai, 2018, pp. 28-30.

[14] P. Li and S. Guo, "Incentive mechanisms for device-to-device communications," *IEEE Network*, vol. 29, no. 4, pp. 75–79, 2015.

[15] Y. Zhang, L. Song, W. Saad, Z. Dawy, and Z. Han, "Contract-based incentive mechanisms for device-to-device communications in cellu-lar networks," *IEEE Journal on Selected Areas in Communications*, vol. 33, no. 10, pp. 2144–2155, 2015.

[16] N. Mastronarde, V. Patel, and L. Liu, "Device-to-device relay assisted cellular networks with token-based incentives," in *Proc. IEEE International Conference on Communication Workshop (ICCW)*, 2015, pp. 698–704.

[17] S. Othmen, F. Zarai, A. Belghith, and L. Kamoun, "Anonymous and secure on-demand routing protocol for multi-hop cellular networks," in *Proc. Int. Symp. Netw. Comput. Commun. (ISNCC)*, 2016, pp. 1–6.

Rana E. Ahmed received his PhD in Electrical Engineering from Duke University, USA, in 1991. He is currently working as a Professor at the Dept. of Computer Science Engineering, American University of Sharjah, Sharjah, United Arab Emirates. He has worked as a faculty member at Lakehead University, Canada, and at King Saud University, Saudi Arabia, in the past. He was a visiting faculty member at the University of Ottawa during academic year 2007-08 while on sabbatical leave. He also worked at Research In Motion (RIM) (now known as BlackBerry) and SpaceBridge in Canada in the areas of software testing, ATM switch testing and software quality assurance. His research interests are in the areas of computer networking, computer architectures, fault-tolerant computing, and software engineering.