Lightweight Mobile Ad-hoc Network Routing
Protocols for Smartphones

Md Shahzamal

Macquarie University, Sydney, Australia
md.shahzamal@students.mq.edu.au

Abstract. Mobile Ad-hoc Network (MANET) is one of the promising wireless networking approaches where a group of wireless devices can establish communication among themselves without any infrastructure. MANET has successfully been implemented in the emergency communication, battlefield and Vehicular Ad-hoc Network (VANET) etc. Recently, MANET has also been studied to establish village level off-the-grid telephony system using mobile phones (smartphones). As the mobile phones and other modern electronic devices are increasingly equipped with efficient wireless Wi-Fi devices, phone based MANET implementation will open new horizons for off-the-self services for phones as well as IoT implementations. However, current MANET routing protocols show poor performances in implementing MANET among mobile phones due to the requirements of high memory, commutation power and high energy usage. The performance seriously degrades when the number of phones increases in the network. Therefore, a lightweight routing protocol is the key requirement for successful implementation of MANET using mobile phones. This report presents relevant routing protocol designs and their applicability to develop lightweight MANET routing protocols for mobile phones. In conclusion, we have presented the challenges and research directions in this field.

Keywords: Mobile ad-hoc network · Message broadcasting · Wireless protocols · Delay tolerant network · Internet of Things.

1 Introduction

Mobile Ad-hoc Network (MANET) is a self-reconfigurable and decentralize communication system that consists of a collection of wireless devices (nodes). These wireless nodes can move independently while participating in the network. In the MANET, the nodes not only act as users but also as routers to forward data. Therefore, a source node can send data to the destination node directly or through intermediate nodes when the destination node is not within the communication range. As MANET does not depend on any fixed stations, the network can be formed anywhere at any time. In the deployment of network, available wireless devices such as laptops, PDAs and phones etc. are the main communication resources for executing network operations along with other few
wireless networking devices. As a result, the implementation cost is quite low in comparison with traditional infrastructure based communication systems. Due to such flexibility and potentiality, MANET has intensively been studied to implement networks in the extreme environments where network infrastructure building is impossible or traditional networking is cost prohibitive according to application objectives.

MANETs are widely implemented as the emergency communication system in the disaster area where quick deployment of network is highly anticipated to support recovery operations [2]. Military operation is another scenario where MANET has shown its potentiality to deploy tactical communication network that connect soldier hand-held devices, mobile tanks, distributed sensors and aircrafts [3]. Except these temporary deployments, MANET is also applied in the Vehicular Area Network (VANETs) for traffic management and route conditions dissemination. Recently, MANET has been investigated to establish village level telephony system using mobile phones. This telephony system provides cost free services such as text messaging and VOIP call among villagers without traditional network [4,5]. This is being considered as an alternative communication system for rural area in developing countries. Mobile phone based MANET (Phone-MANET) has created a new horizon for developing off-the-self services of phones. These services include content sharing among a community, messages dissemination in the conferences, convention centres and shopping malls and lecture distribution in the classroom etc. [25]. As this is the off-the-grid communication among mobile phones, the services are cost free and reduce the traffic load for infrastructure based network. Phone-MANET could also be combined with the forthcoming Internet of Things (IoT) and hence improves the services of IoT.

Although information sharing among mobile phones through direct communication is not new. This peer-to-peer (P2P) communication service is available with mobile phones via Bluetooth technology for long time. Mobile phones can share photos or videos using this technology over short-communication range. Current Bluetooth technology can maintain file sharing among a group of seven devices [6]. 802.11 Wi-Fi can also be used to implement peer-to-peer sharing among phones as the Wi-Fi standard supports ad-hoc mode along with infrastructure mode. The Wi-Fi technology offers much higher data speed and communication range than Bluetooth. However, WiFi enabled phones can only make ad-hoc network within one hop. The modern electronic devices are increasingly equipped with Wi-Fi devices and communication among these devices is highly desired in many applications. But, 802.11 Wi-Fi cannot establish efficient device-to-device communication. Due to this lack of existing solutions, a new approach of Wi-Fi called Wi-Fi Direct has been proposed. This technology operates communication among a group of phones mimicking the approach of access point (AP) based communication. In a group, a device takes over the role of AP that is called P2P Group Owner (P2P GO), while other devices are P2P clients which communicate through P2P GO. The Wi-Fi Direct enabled devices can act as both P2P GO and P2P client. One group can connect with other group being
client to that group. However, the P2P Clients cannot connect more than one
group and P2P client cannot be P2P GO for its GO [7]. This prohibits scal-
ability of the network. As the Wi-Fi Direct enabled devices cannot be client
and router for each other, MANET routing protocol cannot function on Wi-Fi
Direct. Besides, Wi-Fi Direct is required to configure manually. Therefore, it
cannot implement self-organised network [8]. As the peer-to-peer communi-
cation among mobile phones would play a vital role in the future communica-
tion arena, researchers have moved to make a generalised solution. The research has
drifted to modify the 802.11 Wi-Fi radio available with phones for multi-hop ad-
hoc communication. As many smartphone manufacturers have open the source
codes of operating system, multi-hop can be achieved by modifying the Wi-Fi
driver.

The authors of [9,10] have modified the Wi-Fi radio of smartphones and im-
plemented multi-hop ad-hoc mode within. With these developments, phone-to-
phone communication became fully self-organized and MANET routing protocol
can be implemented. However, the network size still remains very small. The rea-
son is that current MANET routing protocols require huge computing power,
energy and memory that phones cannot provide. The previous phone-MANET
base projects have adopted the popular MANET routing protocol called Op-
timised Link State Routing Protocol (OLSR). OLSR works pro-actively where
every node maintains full routing paths to every destination in the network.
Nodes achieve this global information maintenance by periodic flooding of link
information about its neighbours. Route reconstruction is done continuously
based on this flooded information. In this protocol, phones are required to store
information about the entire network topology when they take part in MANET.
This is the main bottleneck to implement MANET over phones. When the num-
ber of nodes increases the network performance degrades sharply. Besides, this
protocol drains phones energy quickly as this protocol generates huge control
overhead. The control overhead is generated as any change in the network is
flooded into the entire network. Therefore, to make successful MANET appli-
cation using mobile phones, protocol should be such that phones are not required
to store the whole network topology to establish paths to the destination and
control overhead would be limited.

In this study, we have presented some popular MANET routing protocols
that can be considered to address lightweight routing protocol for smartphones.
In the section-II, we have described the state-of-the-arts of relevant protocols
and section-III has presented the open issues in this field. We have concluded
our study in the Section-IV.

2 Approaches to Lightweight Protocols

In the context of implementing MANET over smartphones, lightweight routing
protocols refer those protocols that require minimal memory for routing table,
less computing resources as well as generating less protocol control overhead.
Reactive routing protocols which initiate route finding on demand do not main-
tain routing table. These protocols can provide lightweight routing protocols, but their convergence time is high and often create loops in paths [11]. Therefore, the proactive protocols that do not depend on global network information or hybrid protocols that combine proactive and reactive protocols can be good candidate. In the following paragraphs, we have described the relevant methods.

2.1 BATMAN Routing Protocol

Better Approach to Mobile Ad hoc Network (BATMAN) is the routing protocol designed for MANET that does not maintain full path to the destination. Each node only collects and maintains the information about the best next hop towards all other nodes in the network. Nodes collect this information through hello packets, known as originator messages (OGMs), broadcasting by every node periodically. The OGMs at least contain the information about the originator address, sender address and a sequence number. Upon receiving a new OGM from neighbours, a node checks the sequence number and rebroadcasts OGM replacing its own address to the sender address if the message was not received before. The node also keeps track of which neighbour has sent the maximum number of OGM messages from an originator for a period called window time. The respective neighbour is considered as the best next hop to the originator node. When a node has data packet to send to a given destination, it will forward the packet to the best neighbour who forwarded maximum OGM messages generated by the destination node. The process is repeated in the next hops and data packet is delivered to the final destination. This protocol removes link for a node if the OGM message from that node is not received for a time-out period [12]. As the protocol does not keep complete routing paths to the destinations, the protocol is suitable for storage constrained devices. Best next hop selection over a window time and validation of links for a time-out period avoid routing loops. Since this protocol depends only on hello packets and does not broadcast topology change messages, the control overhead is low. However, this protocol also degrades performance when the network size grows and nodes mobility increase. This is because nodes cannot be updated accurately and quickly about other nodes. Therefore, the packet drop increases as it cannot find the destination node. The situation is improved by the authors of [13] who have proposed to add a reactive process when the packets do not find the next hop at the source or in the path to the destination. Reactive process broadcasts request RREQ within a zone of node where a packet does not find the next hop to check which nodes have the next hop to the destination. Then the protocol forwards the packet to that (which has the next hop). This modification improved the performance of BATMAN protocol. However, there are more chances to set up infinity forwarding states as rebuilding next hop cannot guarantee the delivery of packet to the destination.
2.2 Zone Based Routing Protocols

In the zone based routing protocols (ZRPs), each node is only required to know the nodes that are within a specified hop distance. This property is highly desired for memory constrained devices. In these protocols, a zone is created with the centre at the node and a radius of specified hop distance. Each node maintains paths to every node within its zone through an Intra-zone Routing Protocol (IARP). This IARP could be any proactive routing protocol. When the destination node is outside the zone, the path set-up is reactive. To find the routes outside the zone, node first sends a route query to the border nodes on the periphery of its zone. If the border nodes find the destination nodes in their own zones, they send back a route replay on the reverse path. Otherwise, it rebroadcasts the route query to their border nodes again and the process continues until the destination is found. The broadcasting from border to border is called Bordercasting. The global route discovery is done using Inter-zone Routing Protocol (IERP) and Bordercast Resolution Protocol (BRP). IERP is usually the enhanced version of reactive protocols that can discover and maintain routes depending on the link information provided by IARP. BRP also utilises topology information of IARP to direct query request to the border of the zones. BRP employs a query control procedure that avoids rebroadcasting of query to the areas of network that have already been covered [14]. This protocol reduces the control overhead of proactive routing protocols as well as path finding latency of reactive protocols.

Several protocols have been developed based on this basic approach. AOHR (AODV and OLSR Hybrid Routing) is one of the ZRP based routing protocols where nodes use OLSR to set up paths inside the zone and a modification of AODV for outside the zone [15]. Zone radius is selected dynamically by AOHR to be applicable in various network scenarios. The modified AODV uses Multi-point Relaying (MPR) for boarder-casting the global route query. This reduces the control overhead than the basic ZRP. This protocol is lightweight in terms of memory requirements and overhead control. The AODV rediscovers the route newly if the path is broken during data transmission. Besides, the routing path to the destination outside the zone is not the shortest path as the paths are created through border nodes of traversed zones. This decreases the network throughput and packet delivery ratio. The situation becomes worse for the dynamic networks. The authors of [16] have proposed the Genetic Zone Routing Protocol (GZRP) that addressed this limitation of AOHR. The border nodes maintain multiple optimal or sub-optimal paths for the destination node inside the zones. These paths are found by a genetic algorithm that borders node apply on the topological database available with them.

2.3 Cluster Based Routing Protocols

Clustering is another approach to divide the network into groups of nodes that are geographically close. Each cluster selects a head that coordinates its activities. The cluster also selects some nodes on the periphery of cluster as gate-
ways that are responsible for intercommunicating among clusters. For establishing communication outside the cluster, cluster heads can communicate with each others [17]. In the zone based routing protocols, the zones are overlapping whereas the clusters are separated from each other. Therefore, control messages may traverse over more than one zone in ZRP. On the other hand, control messages are restricted within the cluster and hence clustering techniques could reduce more routing control overheads. The performance of the cluster based routing protocols depends not only route discovery and route maintenance but also on the cluster formation mechanism. The route discovery is done by using either proactive or hybrid methods that combine proactive and reactive processes. Cluster formation is done using tree formation, maximum node degree based head selection and hop-distance based clustering etc. As the protocols can operate with the partial view of network, this provides the possibility to develop efficient MANET routing protocols for smart-phones. The following paragraphs have described the popular cluster based routing protocols.

Clustering based on the tree formation is a popular way of grouping nodes in the MANET. The authors of [18] have made clustering based on the tree formation where roots of the trees are cluster heads and the leaf nodes that have neighbours from other clusters are the gateway nodes. The plain OLSR protocol is applied inside the cluster to find the path. Another upper level OLSR is applied among the cluster heads. The cluster heads know the link state information that other nodes have. The cluster heads maintain the paths to the nodes that are in other cluster. For communicating with the nodes outside the cluster, node sends data through cluster heads. The size of routing table for cluster members becomes smaller and routing control overhead is also reduced as topology change broadcasting is restricted within the cluster. However, cluster heads require more storage and computing power as well as tree maintenance produce overhead. This approach is suitable for heterogeneous network where there are some resourceful devices. The authors of [19] have proposed protocol called Cluster-OLSR (COLSR) that is independent of underlying clustering algorithm. Another difference from the previous one is that nodes send data packets to the respective cluster head for outside communication and then cluster head forwards the data packet to the destination node. In this protocol cluster head is only required to maintain path to other cluster heads. Thus, cluster heads require less resources. In these protocols, cluster heads might have transmission loads to maintain routes for other clusters. To balance the load of cluster heads, the authors of [20] have proposed SA-OLSR that broadcasts the Cluster TC messages over the entire network. The other clusters receive only the first copy of Cluster TC and assess the traversed path by the first copy as the faster and less congested path while other copies are discarded. As the route discovery follows the less congested path and the load of cluster heads becomes balance.

The above cluster based routing protocols use proactive route discovery inside the cluster as well as outside the cluster. These methods provide faster route establishment between source and destination. However, the cluster heads should be special node for extra responsibility. Therefore, routing performance decreases
for homogeneous network like phone-MANET. If the combination of proactive and reactive approach is applied for cluster based routing protocol, cluster heads do not require to store much information. The authors of [21] have proposed a cluster based hybrid routing protocol. In this protocol, the intra-cluster communication is done using proactive routing protocol (DSDV) and inter-cluster routing is done using source routing based reactive routing protocol. When the destination node is not inside the cluster, node sends a route RREQ messages to every cluster through cluster heads. The cluster head that has the destination node sends back RREP through the gateways and cluster heads. In this protocol, clusters do not keep information about the nodes that belongs to other clusters, except its own cluster member nodes. Therefore, requirements of special nodes for cluster head is diminished with the cost of global path finding latency. However, the cluster head is still responsible for maintaining the source to destination information. The authors of [22] have proposed a method to get back RREP through the different paths instead of the paths that has followed by RREQ. This reduces the load of cluster head and the protocol becomes more applicable for homogeneous network.

2.4 Link-State Routing Protocols

The most popular link-state routing protocol is the Optimized Link State Routing protocol (OLSR) [23]. This protocol maintains routes to every nodes in the network. This is done by flooding the link-state information throughout the entire network. OLSR uses an optimization technique to flood the link-state information. This protocol broadcasts a subset of link instead of all links called multipoint relay selector. This subset of links is flooded through the Multipoint Relaying and this reduces the redundant transmissions in the network. These properties make the OSLR more stable than other link-state routing protocols. However, due to its larger routing table size this is not efficient to deploy MANET using memory constrained devices like smartphones. The OLSR is designed for all kind of communication. After tuning some parameters, this can be used to implement network with more nodes. Besides, stable MPR selection will produce less topology control overhead. This could be beneficial for energy constrained devices.

The authors of [24] have proposed a Cluster-Based Link State Routing Protocol (CLSR) that works pro-actively. This protocol does not produce any cluster formation and maintenance mechanism as the clustering is done using routing information. This protocol uses hello messages to forms onehop cluster depending on the node connectivity. The nodes who have the maximum of neighbours becomes head and inform other through the next hello messages and the member nodes inform its neighbour about its cluster head. This protocol uses another message called CTC (Cluster Topology Control) to discover neighbour clusters. The cluster heads are connected using Connected Dominating Set (CDS) to form a virtual mesh backbone. Cluster topology information is broadcasted through the gateways. The cluster heads make the routing table only on behalf of the cluster members. That reduces the routing table size.
Mobile Ad hoc Networking (MANET) among smartphones is the new dimension of wireless communication. Researchers have already managed to integrate multi-hop ad-hoc communication mode with the 802.11 Wi-Fi radio of smartphones [25]. However, mentionable research has not been done to develop appropriate routing protocols for implementing MANET using mobile phones in the bigger domain. Most of the previous smartphones based MANET projects [9,25] have applied OLSR and can only manage network for few users. In this report, we have presented some relevant protocols. Different protocols have different prospects for implementing phone-MANET over various network environments. BATMAN is one of the simplest MANET routing protocol. This protocol just maintains the best next hop to every destination and produces very low control overhead although this works pro-actively. This has the characteristics to be applicable for phone-MANET routing protocols. However, this protocol is not much scalable. This is because when the network size grows, the OGM messages are required more time to notice other nodes about its presence. The nodes which do not get updated within the time-out period will delete routing information to the nodes. The mobility of nodes also affects the performance of this protocol significantly. As the forwarded packets will lose the way if the node changes its position quickly in the horizontal direction. The modification of BATMAN [20] can improve for certain network size. After that the protocol becomes fully reactive and loop creations will occur more often due to the internal mechanism of BATMAN. If the directional information of movements is combined with the best next hop selection, the performance could be improved. The BATMAN protocol will outperform other protocols where the node movements are low and MANET services are not real-time. The BATMAN protocol can also be applied inside the cluster instead of OLSR in cluster based routing protocol that would reduce routing table size and control overheads significantly.

Network segmentation is a good way to reduce storage requirements for routing. However, in the ZRP each node is required to run three protocols (IARP, IERP and BRP) for network operation. That will increase computational load as node number grows. As the network size goes up, the zone radius increases too, optimisation by Bordercasting protocol will also reduce as the target border nodes will shift position and became border nodes of other zones. This also increases the uncertainty of finding destination nodes. The situation can be controlled keeping the radius low. However, the latency of path finding will increase significantly as well as will increase the control overhead. The zone routing protocol does not maintain shortest paths between source and destination. The authors of [22] have proposed to use genetic algorithm (GA). But, GA usually requires complex computation that could not afford the smartphones. Simple alternative path maintenance procedure is required for the improvement of ZRP routing protocols. This protocol is suitable for the environment where all participating nodes have the same communication capability. Other network partitioning method is clustering that requires special nodes as cluster heads when the protocol is proactive. This approach performs well for the heterogeneous
networks. That is not suitable for phone-MANET, if the network does not have support from other resourceful devices. If the hybrid approach is assumed, the requirement of special node as cluster-head is overcome. As the cluster based routing protocols depend on the cluster heads and gateways for data packet transmission, the mall-functioning of these nodes will drop the packets. Due to mobility of nodes, maintenance of cluster increases and more control overheads are generated. Moreover, exchanging the responsibility among nodes affect the routing performance as the cluster heads and gateways change frequently due to node mobility. Proper load distribution, reduction of cluster head responsibility and application of route chasing techniques would provide better performance. The cluster based protocols generate less overheads than ZRP routing protocols. These protocols are more scalable than other protocols.

The authors of [24] have proposed a link-state routing protocol that does not depend on other protocols like ZRP or CBRP. This protocol reduces the control overhead significantly and routing table size comparatively small. However, the routes can be often broken as the routes are established over the cluster heads that change frequently due to nodes mobility. The another reason is that clusters are formed using only one hop neighbours in this protocol. Stable cluster formation will improve the situation. This protocol is suitable for implementing routing protocol for resource constrained devices like smartphones. This protocol is not scalable, but scalability can be improved applying technique of ZRP and managing cluster members to handle different parts of the zone through the coordination of cluster head. On the other hand, OLSR is quite stable among the MANET routing protocols. However, the routing table size is bigger than other protocols and the control overhead increases for the dynamic network. This protocol outperforms than other protocols when the network size small.

4 Discussion

Smartphone based MANET has good prospects to play a vital role in the future wireless communication systems. However, the deployment of such network in the wider context is not trivial as the current MANET routing protocols are not directly applicable. The resource constrained of the smartphones prohibits us to adopt the available routing protocols. The main challenges are routing table size and protocol control overhead reduction. There are some protocols that can be modified and combined to design lightweight routing protocols. The combination of clustering and zone routing can improve the scalability of cluster based routing protocol. Besides, management of mobility is the crucial factor in MANET protocol designs. Therefore, proper techniques are required for handing the mobility that will provide efficient phone-MANET routing protocol.

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