Towards DHT-Based P2P Resource Sharing Over Hybrid Infrastructure of Wireless Mesh Network and Mobile Ad hoc Networks

Shabir Ali, Shashwati Banerjea, Mayank Pandey and Neeraj Tyagi

Abstract With the sudden proliferation in the usage of mobile devices, the demand for Internet connectivity is increasing at a fast rate. The public places like the university campuses, railway stations, airports and shopping malls, etc. are facing the challenge of providing uninterrupted Internet connectivity. Wireless mesh network (WMN) presents themself as an elegant alternative for this purpose. These networks exhibit self-organization, self-healing and self-maintenance capabilities. Further, they have less procurement cost and are robust. Also, the mobile devices which are equipped with wireless interfaces can form their own mobile ad hoc network (MANET) which can act as an extension of wireless mesh backbone. This enables to extend the reachability of WMN towards dead zones having no wireless network coverage. In this paper, we propose an approach to combine MANET and WMN. The combination of two types of wireless networks forms the underlay for deploying structured Peer-to-Peer (P2P) applications for resource sharing among the nodes. We have outlined the challenges and propose some possible solutions. Simulation results suggest the applicability of our approach.

Keywords Wireless mesh network · Peer-to-Peer network · Dead zones

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1 Introduction

The Peer-to-Peer (P2P) technology is envisaged for sharing resources over distributed nodes. These distributed nodes create a logical network over an existing wired or wireless physical underlay network. Due to the rapid proliferation of mobile devices, the physical network is generally wireless. The wireless network can either be infrastructure-based, ad hoc network or hybrid network. The infrastructure-based wireless networks such as WLAN and WMN suffer from the problem of "dead zones". Dead zones are the regions where the signal strength is weak (due to hindrance of walls, trees, doors, windows, etc.) limiting the network connectivity. The electronic gadgets are well equipped with wireless interface. The users in these dead zones can create MANET to share resources.

A MANET is characterized by dynamic self-organized multi-hop wireless network of mobile nodes. The mobile nodes collaboratively forward the data in multi-hop fashion. The routes are made either using reactive [1–3] or proactive [4, 5] routing mechanism. These routing functions are implemented at layer-3 of Internet protocol stack. Further, the MANETs are utilized in the absence of network infrastructure for sharing of resources. The structured P2P applications are popular communication protocols for resource sharing over MANETs. The mobility of nodes may produce isolated disjoint P2P logical overlay network as depicted in Fig. 1. This disjoint logical overlay limits the domain of resource sharing and searching.

To connect the disjoint MANETs, we have utilized infrastructure-based wireless mesh network [6]. The nodes of WMN have low mobility and communicate in multi-hop fashion. WMN uses layer-2 of Internet protocol stack to routing information for transmission of data in multi-hop.

We have designed a DHT-based resource sharing system over a hybrid underlay of WMN and MANET. The challenges involved in the design are as follows.

- The Ieee802.11s draft [7] claims that the mesh portal (MPP)/gateway is used to provide the connectivity to other networks. However, it does not have proper implementation details of MPP. This makes provision of connectivity to other networks difficult.
- In wireless mesh network, the routing is done at layer-2 of Internet protocol stack which means it is based on MAC addresses. While in MANETs, the routing is done at layer-3 of Internet protocol stack using IP addresses of source and destination. The implementation of routing mechanism at different layers creates hindrance in providing communication between MANET and WMN.

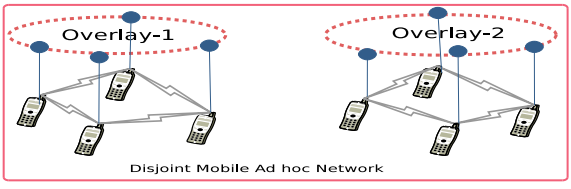


Fig. 1 P2P overlay formation over disjoint MANETs

- Providing the connectivity and reachability of wireless environment in a manner so that it should not result in disjoint DHT-based overlay.

In this paper, we have used an integration of the networks to remove dead zones and to extend the wireless network coverage as needed. We have selected MAP of infrastructure-based WMN as an anchor node for routing between WMN and MANET. Our anchor node has provision of connecting both the networks, i.e. MANET and WMN. We have implemented a table-driven approach at mesh access points. This anchor node provides bridging facility which results into a single logical overlay ring. We have evaluated performance of disjoint overlays in both the scenarios (with/without anchor node). Results suggest that our approach is more stable and scalable.

The remainder of this paper is organized as follows: In Sect. 2, we present works that are closely related to our work. Section 3 explores the formation of P2P overlays over the hybrid wireless network. The simulation set-up is discussed in Sect. 4 and results are discussed in Sect. 5. We have concluded our work in Sect. 6.

2 Related Work

First, we have divided the related work into two parts to accomplish our objective. We explore the works which are focused towards the removal of dead zones [7–12]. Next, we discuss the efforts that have been made for the formation of P2P overlays using hybrid infrastructure of wireless networks [13–16].

In the papers [9, 10], authors have used wireless mesh network to increase the network coverage range of wireless network from few metres to several kilometres in disaster and rural areas. They augmented WMN and geostationary satellite to access the Internet. However, they have not considered the smaller distributed dead zones in scenarios like university campus and smart city. MANET has been prominently used to eliminate dead zones in the paper [8]. Another paper [12] also suggests that the WMN is an elegant solution to extend the network coverage. The integration of networks (WMN and MANET) have been explored in [7, 11] using mesh point portals (MPP). Again both the papers do not provide proper details of implementation.

Several authors [13, 14, 16] have proposed the idea of merging the disjoint cluster of overlays. The authors in [13, 14] have proposed the merging of DHT overlays using cross-layer approach at application layer itself. These works are significant when the mobile nodes are working in same mode (either infrastructure mode or ad hoc mode). Whereas, [16] suggests that dedicated relay node can be placed in close vicinity to Wi-fi which toggles the operating modes. We have also adopted similar method to connect MANETs and WMN using anchor nodes. The major difference in our approach is that we have considered mesh access point as anchor node which has negligible mobility. Whereas, in previous work [16] the relay nodes are the nodes of MANET which have no predictable mobility. Another major problems in selecting mobile nodes as relay node for transmission of data are either mobile nodes have

dual wireless network interface card or software level toggling of modes. Both the approaches required customization of mobile nodes which are not feasible solution due to restriction of access.

3 Formation of P2P Overlays Over Hybrid Wireless Network

The P2P resource/message sharing applications can be deployed on smartphones, laptops, PDAs, etc. Each of the mobile devices is equipped with wireless interface. The wireless interface can be utilized to form a MANET. Thus, disjoint MANETs are formed in different dead zones as shown in Fig. 1. These island of MANET have to be connected through infrastructure-based network for exchanging overlay messages. WMN and WLAN are popular infrastructure-based network. WLAN has last hop wireless connectivity, which limits the network coverage. Moreover, the backbone of WLAN is wired which makes the technology costly. On the contrary, WMN is easy to extend.

Figure 2 depicts the scenario, where the disjoint MANETs are connected with infrastructure-based WMN. The data transmission between two disjoint MANETs is conducted in two phases. In first phase, data travel through the first MANET in multi-hop fashion to hand over this data packet to wireless mesh network. In second phase, the data travel through WMN to reach the appropriate node to hand over these data packets again to second MANET. MANET uses layer-3 Internet protocol stack to decide the path to destination. Further, the wireless mesh network uses layer-2 of Internet protocol stack to transmit the messages to destination with in WMN. The differences in routing layers motivate to create a node which transparently handles the routing mechanism for both of the networks, i.e. WMN and MANET. We have created a node called as anchor node which handles the routing job and connects these networks.

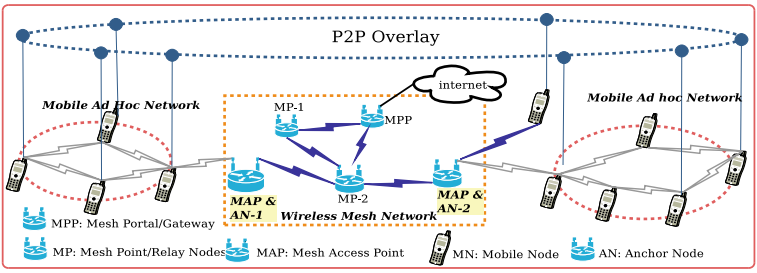


Fig. 2 P2P overlay formation over hybrid network of WMN and MANETs

3.1 Anchor Node: Multi-wireless Interface

The participating nodes of MANET are smartphones, laptops, PDAs, etc. which equipped with wireless network interface card (NIC). This wireless NIC operates in ad hoc mode to form a MANET. To install wireless mesh network, there are four kinds of nodes in WMN: end station (STA), mesh point (MP), mesh point portal (MPP) and mesh access points (MAP). The interconnected MPs form the backbone of the network. MAP is an endpoint of attachment with two wireless network interface card (NIC), one NIC is used to connect end devices such as smartphones, laptops, PDAs, etc. (operating in infrastructure mode with standard 802.11 capability) and, other interface of MAP is used to connect MPs (operating in ad hoc mode with 802.11s mesh capability). Mesh portal (MPP)/gateway nodes facilitate to connect external networks and Internet. We have used a responsible node for routing and data transmission known as "Anchor Node".

The anchor node is mainly designated machine for connecting MANET and WMN. These anchor nodes could either be separately implemented for this purpose or one of the nodes of WMN. We have considered mesh access point of WMN as anchor node because of negligible mobility of this device. As mentioned before, the anchor nodes must operate in dual mode to provide the both kind of connectivity, i.e. infrastructure and ad hoc mode simultaneously. To achieve said target, we attached one additional wireless NIC in mesh access point to provide both kind of connectivity. The anchor node can be placed with in the wireless range of MAP. It can also participate to form overlays. Due to static nature of anchor node, the P2P network produces high stability of overlays.

4 Simulation Setup

In this section, we have described the simulation of peer-to-peer application over hybrid network with and without anchor node as shown in Figs. 1 and 2. Our integrated framework [17] platform comprised of modules of OverSim, INETMANET 3.0 and OMNeT++ 4.6. We have utilized chord (the most popular structured overlay protocol) which builds a ring-based topology of nodes and uses a distributed hash table (DHT) of nodes to perform routing (iterative/recursive) of overlay messages across the overlay ring.

Our integrated framework uses "KbrTestApp" [18] application (based on chord protocol) in overlay nodes to test the reachability between overlay nodes. The "KbrTestApp" performs one-way test by sending PING and PONG messages between the overlay nodes. To measure the performance of chord overlay, we have evaluated "KbrTestApp" application over the underlying MANET. The MANET nodes are forming routing path using a reactive routing protocol DYMO [19]. The WMN underlay uses hybrid wireless mesh routing protocol [20]. To mitigate the mobility model, we have opted random waypoint mobility [21] to control the move-

Table 1 Simulation settings

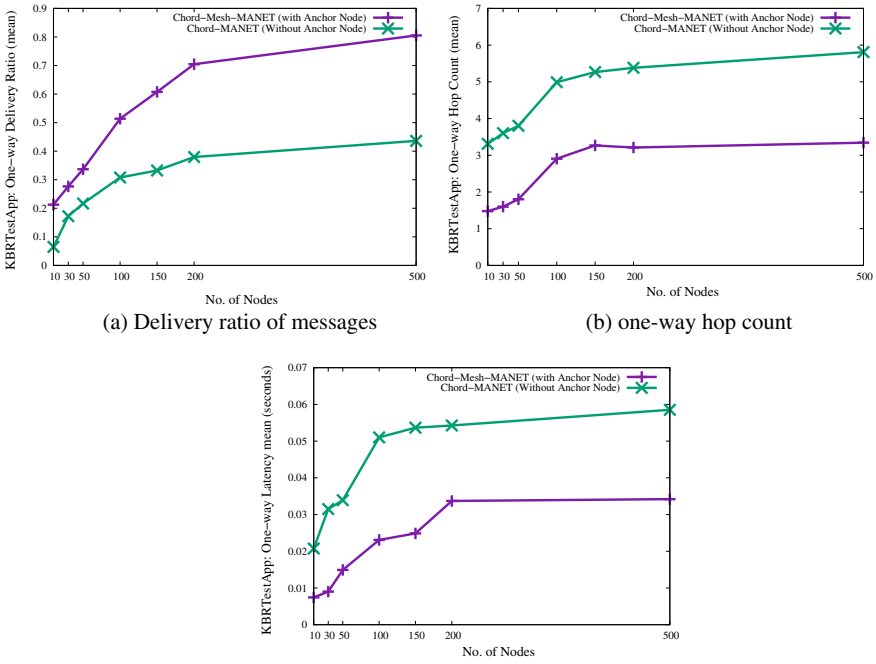
Simulation parameter	Value
Simulation area	2000×2000 m^2
No. of nodes (with and without anchor node)	10, 30, 50, 100, 150, 200, 500
Overlay protocol	Chord
Tier-1 application	Dummy
Tier-2 application	KbrTestApp
Overlay routing	Iterative
Transport layer protocol	UDP
MAC layer	IEEE80211SMAC
Underlay routing protocol	HWMP (layer-2), DYMO (layer-3)
Data rate	54 MB/s
Transmission range	100 m

ment pattern of mobile nodes. We have also utilized no churn model [18] (in which the nodes only join the scenario periodically) to realize the churn dynamics. Further, the stationary mobility model is utilized for simulating the wireless mesh network of fixed nodes. The chord overlay uses key-based routing (KBR) test application [18] as Tier-1 application to test the routing of messages to peers. Table 1 shows the main settings for our simulation set-up.

5 Result and Discussion

This section is intended to discuss the results obtained from our implemented framework. The findings are discussed in terms of mean delivery ratio, one-way hop count and latency of messages chord overlay. The measurement is taken against varying node densities in both the topology as in Figs. 1 and 2. The mean delivery ratio is recorded for one-way test messages sent by the KBR test application running on each overlay terminal. The hop count of overlay messages is measured in terms of mean number of overlay hop count using iterative/recursive routing to reach the destination. We have also recorded mean of latency of overlay messages to reach the destination. We have carried out simulation for two configurations. Every configuration was repeated 10 times in each run.

The performance outcomes are shown in Fig. 3a–c. First set of results was recorded for MANET topology without anchor nodes as in Fig. 1 with random mobility of nodes. Wherein we observed maximum of 42% delivery ratio for node densities of 10, 30, 50, 100, 150, 200 and 500 nodes (Fig. 3a). Another set of results were recorded for MANET topology with WMN and dedicated anchor node (Fig. 3a) with stationary mobility of WMN node (including anchor nodes). In the presence of anchor node, a rapid increase in the performance was seen with increase in node



(a) Delivery ratio of messages

(b) one-way hop count

(c) Latency of messages

Fig. 3 **a** Delivery ratio of messages, **b** one-way hop count, **c** latency of messages

densities from 10 to 500 nodes, i.e. delivery ratio increased from 42% to almost 82%. On the other hand, the overlay hop count and latency decreased on increasing the node densities (Fig. 3b) from 5.2 hop count to almost 3 hop count and latency decreased from 6 to 3 ms (Fig. 3c). It is also evident from the plots (Fig. 3a–c) that the performance of chord overlay stabilizes when the node density in the constraint area reaches a certain level.

The results so obtained are in complete accordance with and without anchor nodes which resulting in desired performance of chord overlay over disjoint MANETs. These results are comparable with similar works done in [16, 22].

6 Conclusion

We have proposed an approach for the removal of dead zones by forming MANETs in conjunction with the infrastructure-based WMN. The logical overlay of P2P application running over MANETs in dead zones is split due to unavailability of MANET network coverage. The split of overlay ring results in restrict to search domain. We have proposed WMN-based approach to merge the logical overlay. WMN also poses

challenges to provide connectivity to MANETs. We have used an anchor node to provide the connectivity to MANETs for merging disjoint overlays. The work is useful in scenarios like university campuses, smart city, rural area, etc. The results obtained from simulation suggest the applicability of work in similar context.

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