A Cellular-Based Routing Algorithm for Ad-Hoc Wireless Networks

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Abstract — In this paper we present a routing algorithm when an Ad-Hoc network is in the coverage of a cellular network. To perform routing in Ad-Hoc network, the proposed algorithm exploits topology information of Ad-Hoc network that obtained from Base Station in cellular network. Two routing scenarios regarding to Ad-Hoc nodes capability are considered. Cellular network is just used to accomplish routing for Ad-Hoc network. After performing the routing through the centralized management system in cellular network, requester Ad-Hoc node forwards data via its Wi-Fi interface according to the discovered route in the Ad-Hoc mode. Our results show that the proposed routing protocol outperforms pure AODV and DSR protocols in terms of end-to-end delay, routing overhead, and packet delivery ratio.

Keywords — Ad-Hoc networks, cellular networks, QoS, routing, Gateway node.

1. Introduction

Future wireless networks try to provide a ubiquitous environment that users can access to desired services. In these networks, the network nodes are equipped with interfaces enable them to operate in supported networks. Heterogeneous mobile nodes are able to operate in different networks by using the relevant interface. Admittedly, seamless connection must be supported when users roam between different networks.

Cellular communication technologies are widespread very fast in the world. A cellular network is a radio network made up of a number of cells each served by a fixed transmitter, known as a cell site or base station. Base stations arbitrate the channel allocation between the mobile stations. Cells are used to cover different areas in order to provide radio coverage over a wider area than the area of one cell. These networks consist of a collection of mobile stations served by a central coordinating entity called BS. Furthermore, these types of network benefit from extensive covering range and access to centralized management system but low data rate. They are also able to access to backbone and core of the Internet.

Another type of wireless network is Ad-Hoc network. Mobile Ad-hoc networks (MANETs) are mobile data networks, which are made up of a number of mobile nodes that are self-configurable. MANETs have high data transmission rate, multi-hop transmission, and fast deploying characteristics. They are capable to perform routing in distributed way. These attractive features of these networks make them a good candidate to provide a seamless method of communication when infrastructure and backbone dose not exist to exchange data in high speed data rate. These networks don't have any infrastructure such as Base Station (BS) or Access Point.

One of the most challenges in wireless Ad-Hoc networks is designing routing algorithms which consider QoS constraints. In these networks, high frequency of route breaking caused by mobility of nodes deteriorates the provided QoS.

By integrating of cellular and Ad-Hoc networks features, better performance can be achieved. In order to design an integrated cellular and Ad-hoc network there are several motivations. Firstly, APs are becoming ubiquitous and laptops and many PDAs and other communication devices are equipped with Wi-Fi. Also cell phone manufactures offer smart phones that can operate in Ad-Hoc and cellular modes. Recently, communication devices are equipped with multi-interface network cards that enable them to access different networks. Regarding to the requested QoS, devices can switch to the best service by using the related interface. Secondly, users can achieve higher throughput by switch between desired services in integrated network by using corresponded interfaces. Thirdly, in the most locations, Ad-Hoc networks are in the coverage of cellular networks. Finally, users and service providers can procure several advantages.

Further more, by integrating cellular and Ad-Hoc networks, Ad-Hoc network can use centralized management belongs to the cellular network for carrying out Authentication, Authorization and Accounting (AAA) mechanisms.

The rest of this paper is organized as follows: Section 2 covers related work. In section 3, two algorithms related to cellular-based routing in Ad-Hoc network are proposed. Then, the experimental results are provided in Section 4. Finally, the paper is concluded in Section 5.

2. Related work

Several protocols have been proposed to integrate cellular and Ad-Hoc networks. Most of the related works in this area try to improve throughput, coverage extension, and load balancing of cellular networks. They also attempt to decrease transmission power of nodes by using combination of Ad-Hoc and cellular networks. In this study, proposed algorithms exploit cellular network to perform routing for Ad-hoc
network when an Ad-Hoc network nodes are covered by a cellular network. This integrated scheme leads to finding the better routes with QoS-routing parameters consideration.

In this section some architectures regarding to cellular and Ad-Hoc networks integration are briefly described.

Wu et al. propose an Integrated Cellular and Ad-Hoc Relaying (iCAR) architecture [1]. The goal of iCAR is to balance load between BSs in cellular network by exploiting the special Ad-Hoc nodes named Ad-Hoc relay system (ARS). ARSs act as gateway to relay excess traffic from a hot spot cell to a lightly loaded cell in its vicinity. These gateways are deployed in planned positions and MS can only use one hop away GNs. MADF (Mobile Assisted Data Forwarding) has a similar architecture to iCAR, but it does not use preplanned ARSs [2]. MADF uses MNs to divert excess traffic between cells.

Ananthapadmanabha et al. propose a Multi-Hop Cellular Network (MCN) that is used to enhance the BS throughput [3]. In this architecture a connection is founded between source and destination through a multi-hop path in the same cell. BS or AP selects the operation mode and executes a centralized routing algorithm.

A similar architecture to MCN is UCAN[4]. Unified Cellular and Ad-Hoc Network is proposed by Luo et al. In UCAN, MSs search for gateway nodes when their transmission rate decreases to below a given threshold. The main optimization goal in UCAN is to reach BS throughput and user downlink data rate.

Zadeh et al. propose SOPRANO (Self-Organizing Packet Radio Ad-Hoc with Overlay) [5]. This architecture benefits from inexpensive routers in the cellular structure to achieve the target capacity obtained by the cell splitting technique. Providing high data rate Internet access via inexpensive relays and maximizing the network capacity by choosing a suitable routing strategy are main goals of SOPRANO. In SOPRANO routing decision is based on minimum interference and energy. Load balancing and BS zone extension are other benefits of this architecture.

Dual-mode MSs in the Ad-Hoc Global System for Mobile Communications (A-GSM) architecture relay packets in Ad-Hoc mode and connectivity could be achieved in hot spot areas [6]. A-GSM uses a proactive scheme. These GNs transmit beacon messages to advertise their capabilities of serving as relay nodes. Maximizing the cell coverage and capacity and transmission power reduction are main optimization goals of A-GSM architecture.

In ODMA (Opportunity-Driven Multiple Access) there is no GN and every node can relay packets. In this architecture routing decision is based on the signal quality [6]. ODMA breaks a single CDMA transmission from an MS to a BS, or vice versa, into a number of smaller radio hops by using other MSs in the same cell to relay the packets. Thereby the transmission power and co-channel interference are reduced and more BS capacity will be achieved.

Other architectures such as HNA [7], Two-Hop-Relay [8], HWN [9], TAPs [10], and BAS [11] are proposed to integrate cellular and wireless networks. In the next section proposed routing Protocol will be described.

3. Integrated Routing Protocol

In this paper two different scenarios have been posed. Regarding these two scenarios, two routing algorithms have been introduced. In the first scenario, all nodes are similar and equipped with both cellular and Wi-Fi interfaces. But in the second scenario, there are two types of nodes, some nodes have both network interfaces and the others are just equipped with Wi-Fi. Therefore, in contrast with the first scenario, in which a node directly sends its RREQ to BS, in the second one, the node must search for a Gateway Node (GN) which is a node with two interface cards, and then tries to send RREQ through the nearest discovered GN. Then the GN sends the received RREQ to the corresponded BS. After the RREQ is received by BS, the process of finding route(s) would be similar in both scenarios.

It must be mentioned that cellular network is just used to perform Ad-Hoc routing process. After cellular network does routing in discovery phase, source node sends data in transmission phase through its Wi-Fi interface.

3.1 First Routing Scenario

In this scenario of routing, two possible node positions of dual mode nodes are considered: when a source node is in the coverage of cellular network and when is in out of the coverage of a cellular network. Each node in this scenario, advertises directly its location to the BS via its cellular interface. Figure 1 shows the network behavior in the first scenario. Dashed lines represent the discovered routes.
Figure 2. Route discovery and data transmission algorithm in the first scenario

Route Discovery Phase

- **Source is in the coverage of the BS**
  - If there is a valid route in the cache of the source, go to Data transmission Phase
  - Else, source simultaneously performs:
    - Restricted Ad-Hoc Routing
      Using an AODV or DSR with an adjustable Hop-Count (for example 2)
    - Cellular-Based Routing
      1. Source sends RREQ to the corresponded BS through its cellular Interface
      2. The BS sends RREQ to the BS through its cellular Interface
      3. The BS sends route(s) to the source.
      Receiving the first route response, source starts to send data in Data Transmission Phase

- **Source is out of the coverage of the BS**
  - If there is a valid route in the route cache of the source, go to Data Transmission Phase
  - Else, source simultaneously performs:
    - Restricted Ad-Hoc Routing
      Using an AODV or DSR with an adjustable Hop-Count (for example 2)
    - Cellular-Based Routing
      1. Source selects the best GN between GNs based on their distances
      2. Source sends RREQ to the GN through its Wi-Fi Interface
      3. GN sends RREQ to the BS through its cellular Interface
      4. The BS sends RREQ to the BS through its cellular Interface
      5. The BS sends route(s) to the source.
      Receiving the first route response, go to the Data Transmission Phase.

Data Transmission Phase

Source uses the Ad-Hoc mode (Wi-Fi) to transfer data according to discovered route(s).

According to the proposed routing algorithm described in figure 2, when a source node is in the coverage of a cellular network, at first it starts to search route to destination in its local cache. If there is a valid route to destination, source sends data via Wi-Fi interface to destination. Else, source does a limited Ad-Hoc and cellular-based routings. Concurrent to limited Ad-Hoc routing, using the cellular network to perform a routing, source sends a RREQ to the BS via its cellular interface. Whenever the BS receives a RREQ, it sends this message to the upper layer of cellular network. In the central management system a fixed routing algorithm regarding to the received RREQ and desired QoS will be performed. In this centre, all nodes in Ad-Hoc network are observed as a fixed network because positions of all nodes are available.

When a source node is in out of coverage of the cellular network, it searches a GN to send its RREQ to it. The source calculates power of received signals and selects the best GN as its gateway. Source sends RREQ message to the GN. Whenever a GN receives a RREQ, it performs RREQ to the BS and above procedure executes. After source received route replay from restricted Ad-Hoc routing or Cellular-Based routing, starts to send data via Wi-Fi interface according to the received route.

3.2 Second Routing Scenario

An example of the second scenario is shown in figure 3. In this scenario some nodes are equipped with both cellular and Wi-Fi interfaces.

Figure 3. Route discovery and data transmission in the second scenario

Dual mode nodes act as GNs and Ad-Hoc nodes should search a GN node for relaying RREQ messages to the cellular network. Dual mode nodes can operate in cellular and Ad-Hoc networks via relevant interface. Routing scheme in this scenario is similar to the first scenario when source node is in out of coverage of cellular network.

In this scenario there is no difference between being in or out of coverage of the cellular network. In both states source discovers a suitable GN according to received signal strength received from dual mode nodes. Source node starts to search a dual mode node then sends RREQ to appropriate GN for relaying the RREQ to the cellular network. Figure 4 shows this procedure. Having location of all nodes, routing server can run a centralized routing algorithm (such as Dijkstra) to find the best available route according to incoming request.
We compared proposed protocol results for end-to-end delay, routing overhead, and packet delivery ratio with a similar network environment that runs DSR as its routing protocol. Figure 5, illustrates the delivery ratio comparison of two proposed scenarios with AODV and DSR when number of active links increase. It is clear when the number of active links increase, it causes routing overhead to augment in all routing protocols. In the first scenario, all nodes are dual mode and routing overhead includes routing request, routing reply messages and location advertisements that are communicated through cellular networks.

In the second scenario, 10 percent of nodes are dual mode, routing overhead is lower than AODV and DSR. Routing overhead includes routing request, routing reply messages, location messages, and GN discovery messages. Also, in both scenarios a restricted DSR routing is performed with hop count equal to 2. Therefore the produced overhead is negligible. AODV and DSR employ flooding for route discovery and it causes more routing overhead.

Packet delivery ratio comparison for routing protocols is depicted in figure 6. When the number of active links increases, the delivery ratio for two scenarios, AODV, and DSR decrease, because collision increases in the MAC layer. The first scenario encountered with much lower overhead and delivery ratio in this scenario is approximately 3 and 4 times as large as the AODV and DSR respectively.

When the number of active links increases it causes significant end-to-end delay in AODV and DSR. Main reason is relevant to flooding and collision growing. In the first and second scenarios, collision is much lower than AODV and DSR because of finding better routes and flooding avoidance in the route discovery phase. Although, small restricted Ad-Hoc routing flooding affects end-to-end delay in both scenario but it is not very forcible. Influence of link increasing is shown in figure 7.

Effect of dual mode on end-to-end, overhead, and delivery ratio are presented in figures 8 to 10 respectively when number of active links is constant.
Admittedly, when the number of dual mode nodes increases the probability of finding a node as a GN increases and routing parameters have better operation to achieve desired QoS. Also, in these figures we examine the effect of node velocity on these parameters. High node mobility degrades QoS parameters and if there is few number of dual mode nodes in Ad-Hoc network then QoS degradation is more severe. In high node mobility network encounters with more link breakage and it causes more overhead and end-to-end delay.

![Figure 10. End to End delay vs. number of dual-mode nodes (V=10, 15, and 20 m/s and Active links number=40)](image)

5. CONCLUSION

In this paper, we proposed a routing algorithm for integrated cellular and Ad-Hoc networks. This algorithm utilizes cellular management to discover routes in Ad-Hoc network. Two routing scenarios are proposed. Simulation results demonstrate the effectiveness of our method to achieve QoS parameters. Compared to AODV and DSR, our algorithm is able to establish more optimal routes using cellular management.

5. ACKNOWLEDGEMENT

This paper is partially granted by Iran Telecommunication Research Center (ITRC) and the authors are grateful for their support.

REFERENCES


