AN EFFICIENT ROUTING PROTOCOL TO INCREASE THE COMMUNICATION RELIABILITY OF MULTI-HOP CELLULAR NETWORKS

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ABSTRACT

Reliable routing is important to the reliable communication between end users in wireless networks. However, the infrastructure wireless networks and ad-hoc wireless networks suffer from channel congestion in routings, failing to guarantee high transmission reliability. Multi-hop cellular networks integrating the two type of networks increase the communication reliability by combining the infrastructure routing protocol and multi-hop protocol, but are still prone to congestion at the mobile gateway nodes. This paper presents an Efficient Routing Protocol (ERP) to increase the communication reliability of multi-hop cellular networks. This routing protocol chooses a node with higher channel capacity to forward data to a base station, and the routing path length is adaptive to the channel condition of the forwarding nodes. When a node's channel quality to a base station is not sufficiently high or the buffer size of the node is almost filled in, it chooses a relay node with higher capacity to forward the data to a base station. Thus, the routing protocol guarantees that a message is reliably transmitted to a base station. Simulation results show the superiority of the ERP in comparison with other routing scheme in terms of scalability, throughput and overhead.

1 INTRODUCTION

Over the past few years, the infrastructure based wireless communication network (e.g. cellular network, WiFi) evolves rapidly, which has become the major communication mode in our daily life. These fast developing wireless communication technologies make possible the support of universal network connectivity and the ubiquitous computing by integrating all kind of wireless devices into the network. The infrastructure based network depends on a centralized transmission mode which consists of base stations. In the coverage range of the base station, the mobile nodes can communicate with base station directly. These base stations are connected by a wired backbone. The base station serves as a relay point for the source and destination transmission. That is, if the source node and destination node are in the same cell, the source node transmits the messages to a base station first, which then forwards the messages to the destination node. When the source node and destination node are not in the same cell, the base station serves as a gateway between its cell and internet backbone, assisting the inter-cell communication. The advantage of the infrastructure based network is that the mobile nodes in the cellular network are mobility resilient for their direct transmission feature and do not suffer from network partition. Meanwhile, the centralize control of the infrastructure can improve node's channel accessing efficiency based on some scheduling protocols [1, 2]. However, the growth of traffic and continued proliferation of mobile services will create heavier traffic in cellular system, which causes channel congestion in the base station. It is also prone to the dead spot issue resulted from the neighbor interface or the uncovers of the base station. Moreover, the failure of base station in the system will adversely affect the communication ability of the nodes in that failed cell.

Mobile Ad-hoc Networks (MANETs) are collections of wireless mobile nodes which promise a convenient infrastructure-free communication. In the absence of central control infrastructure, the hosts in the MANETs are communicated in a multi-hop fashion. In the MANETS, the mobile devices can use a short-range transmission interface to send messages to the intermediate nearby neighbor nodes. Adapting to the transmission range that are just large enough to ensure network connectivity allows the mobile nodes in ad-hoc network to maximize spatial reuse [3] (spatial reuse is ability to enable several simultaneous transmissions when they are far enough from each other without interference). Spatial reuse is a very important feature which can greatly increase the capacity of MANETs. Hsieh *et al.* [4] shows that a total end-to-end capacity results from the spatial reuse is about $O(n/\sqrt{n})$ and the end-to-end throughput for each node is $O(1/\sqrt{n})$ [5], rendering a higher throughput by a factor of $O(\sqrt{n})$ to the cellular network with throughput as $O(1/n)$ [4]. Meanwhile, the short transmission distance between neighbor nodes can increase the power efficiency of the system. Suppose the transmission power consuming between the two node increase as the d^k, where k is constant value normally

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between (2-4) and d is the distance between two nodes, then the multi-hop transmission can save as much as $n^{\frac{k-1}{2}}$ energy compared to the infrastructure network. However, it is proved that the ad-hoc network is not suitable for the transmission in a large scale network [6, 7, 8]. Even in a static environment, the end-to-end throughput available to each node is scaling as $O(\frac{1}{\sqrt{n}})$ [9]. Even in a uniform random network with random traffic pattern with a global scheduling protocol, the end to end throughput is $\Omega(\frac{1}{\sqrt{nlogn}})$ [9]. Such low performance mainly results from the congestion losses in the transmission and the interference from their neighbor nodes. In addition, if in a highly dynamic mobile scenario, the network partition and route path failure caused by the node mobility will cause higher message dropping rate [9], which further reduces the capacity of mobile ad-hoc network. The imbalanced end-to-end transmission will also deteriorate the performance of multi-hop transmission.

The growing desire to increase the wireless network capacity for the high performance in the system has produced a significant stimulus to the development of hybrid wireless networks [10, 11, 12, 13]. A hybrid wireless network is a combination of an ad-hoc network and an infrastructure network (e.g. cellular network) in which base stations in the infrastructure network act as relays for wireless nodes in the ad-hoc network to conduct inter-cell communication. Many researches have shown that such hybrid network can reduce transmission power [14], balance the load between the base stations [12], and extend coverage area of each transmission mode [15]. However, although the hybrid network structure leverage the advantages of both networks structure and improve their performance individually, the current routing approaches either introduce more expensive devices such as GPS and proxy or still inherits the shortcomings of the traditional pure ad-hoc network such as network partitions, high routing maintain overhead or one path transmission congestion and prone to the congestion in the gateway node.

The problems become an obstacle in achieving higher communication reliability in hybrid networks. This paper presents an efficient routing protocol (ERP) to increase the communication reliability of multi-hop cellular networks. This routing protocol greedily chooses a node with higher channel capacity to forward data to a base station, and the routing path length is adaptive to the channel condition of the forwarding nodes. When a node's channel quality with a base station is not sufficiently high or its buffer is almost congested, it chooses a relay node with higher base station channel capacity to forward the data to a base station. Thus, the routing protocol guarantees that a message is reliably transmitted to a base station.

The rest of this paper is organized as follows. Section 2 presents a review of representative hybrid networks and multi-hops routing schemes. Section 3 details the proposed routing protocol. Section 4 shows the performance of the routing protocol in comparison with a traditional hybrid network with AODV. Finally, Section 5 concludes the paper.

2 RELATED WORK

In order to increase routing reliability and throughput capacity of wide-area wireless networks, various hybrid networks with different features have been proposed [10, 11, 12, 13, 16] to synergistically combine the infrastructure network and ad-hoc network to leverage the advantages of each other. Most of these hybrid networks directly combine the routing protocols in ad-hoc networks and in infrastructure networks together [13, 17, 14, 10]. In [13], the mobile nodes broadcast query message to find a routing path to the low congested cell for the date transmission. In [17], the authors show the introduction of several base stations can increase the connectivity of the ad hoc network with sparse nodes. In [14], the authors present a multi-hop cellular network, and derive the throughput of multi-hop cellular network and singe-hop cellular network, based on the RTS/CTS access method. In [10], a 3G base station forwards messages to destination clients with poor channel quality to proxy clients with better channel quality. The proxy clients then use an ad-hoc network composed of other mobile clients and IEEE 802.11 wireless links to forward the messages to the appropriate destinations, thereby improving cell throughput. In the modules of [18], before a source node sends data to the destination node, it first sends a number of routes to a base station asking for the best route. The base station replies with an optimal transmission path according to the congestion and channel quality. The base station needs to coordinate the routes between different requesters to avoid congestion. Although this method can find a better routing path, it leads to a high overhead for source nodes to query the routing path and for base stations to coordinate the routes. Moreover, a base station cannot detect the routing path outside the range of itself, and cannot always guarantee the existence of the chosen path in a high mobile environment.

In the hybrid protocols that directly combine infrastructure routing and ad-hoc routing, all data passes through a single mobile gateway node to access a base station for inter-network transmission, which may make the base stations easily become traffic bottlenecks. The majority of routings in the ad-hoc components in hybrid networks rely on traditional ad-hoc routing protocols, such as Ad hoc On-demand Distance Vector (AODV) [19], Dynamic Source Routing (DSR) [20]. In DSDV, each node maintains a routing table and a router informs its neighbors of topology changes periodically. Keeping a complete routing table reduces route acquisition latency for data transmission. However, its correct operation depends on its periodical global dissemination of connectivity information. It has low scalability due to its frequent system-wide broadcasting. The DSR algorithm determines routes on demand. A route is a sequence of nodes that a message needs to traverse from a source node to its destination. In DSR, a route is carried in a data message's header for data transmission. The increase of the package size leads to high message transmission overhead. Moreover, DSR may have incorrect routings due to stale route information, resulting in poor performance especially in highly mobile networks. In AODV, each node keeps a routing table for discovered routes, and nodes exchange routing information to attain the up-to-date view of the network only when they are involved in an active route. It scales well to large networks. However, even though network connectivity update is performed only during an active routing phase, it still increases the signaling overhead of the entire network. DSR and AODV need high overhead for route discovery. They store route information after route discovery. It saves routing maintenance overhead, but often fails to observe the up-to-date network topology changes. These routing protocols incur high channel resource consumption for route discovery and maintenance, leaving less channel resource for data routing and hence exacerbating the routing congestion problem.

In addition, some work employ some pre-determined equipment for the date routing. Hung *et al.* [16] proposed a delicate network architecture for hybrid networks, in which base stations can adjust their transmission ranges for data transmission. However, GPS and single direction antenna equipped mobile stations are assumed in the system, increasing the system complexity. De [12] proposed to place a number of ad-hoc relay stations at strategic positions in order to relieve the congestion of certain cells. Although these works can increase transmission reliability to a certain degree, the equipment required increases the system cost and system complexity. Meanwhile, these pre-deployed stations care easy to be the hot-spot.

For reliable routings, the works in [21, 18] set partial channel resources specifically for data forwarding, and the rest especially for control messages. Zadeh and *et al.* [22] proposed to reduce signal attenuation by decreasing power during data transmission. Wei [23] proposed a two hop routing for the routing for the hybrid network. However, in their proposal, each node just chooses between the nodes in one hop and transmit the messages reducing path length for high routing reliability. Meanwhile, this work only considers the traffic in one cell rather than between the cells.

Algorithm 1: Pseudo-code for the node selection

```
nodeSelection(){
  while (there are more message){
    get all neighbors
    if the current channel quality > each of
      the neighbors nodes channel quality then
    //direct forwarding
      transmit the message to the base station
    else{   //relay forwarding
      if message.TTL > 0 then {
        choose the neighbor node with the highest
        available channel capacity with enough buffer size
        message.TTL−−
      }
      else //the base station is a hot spot
        direct transmit to the base station.
    }
  update the channel information}
```

A considerable congestion control methods have also been proposed in MAC and TCP layer to mitigate the congestion situation in the system, such as CSMA-CA [24], AIMD [25] and etc. These methods can be broadly classified into two categories: end to end congestion control and network assistant congestion control. In the first categories, no explicit feedback from network and the congestion inferred from the end-system observed loss and delay. In the second categories, router will provide feed back to end system about the congestion. However, the efficient congestion control in the MAC and TCP layer is at cost of throughput of the end-to-end transmission.

In our previous work [26], we proposed a distributed routing method (DR) to mitigate the congestion in multi-hop cellular networks. DR tries to mitigate the congestion by forwarding the segments of a message to different cells in a distributed manner. Although both of DR and ERP aim to increase the performance of routing in hybrid networks, these two methods are different in two aspects. First, ERP uses one-directional adaptive routing for message forwarding while DR uses distributed message forwarding. Second, ERP uses TTL to constrain the traffic hops in a routing while DR greedily transmits message segments to the mobile gateway node close to base stations. Third, to enhance routing performance, ERP focuses on choosing optimal nodes to forward messages while DR focuses on forwarding data in a distributed manner.

3 Efficient Routing Protocol

Most routing protocols in multi-hop cellular networks combine the routing protocol in pure ad-hoc network and infrastructure based network. That is, a message is routed by multi-hop routing algorithm until it arrives at a base station via a close gateway mobile node. The base station then forwards the message to another base station where the destination node resides using the infrastructure routing algorithm. Finally the *second* base station forwards the message to the destination. *Mobile gateway nodes* are the mobile relay nodes that connect base stations and mobile nodes. In such routing protocols, the mobile gateway nodes could easily become bottlenecks. The bottlenecks are overloaded due to heavy traffic load, and hence are not able to reliably forward messages.

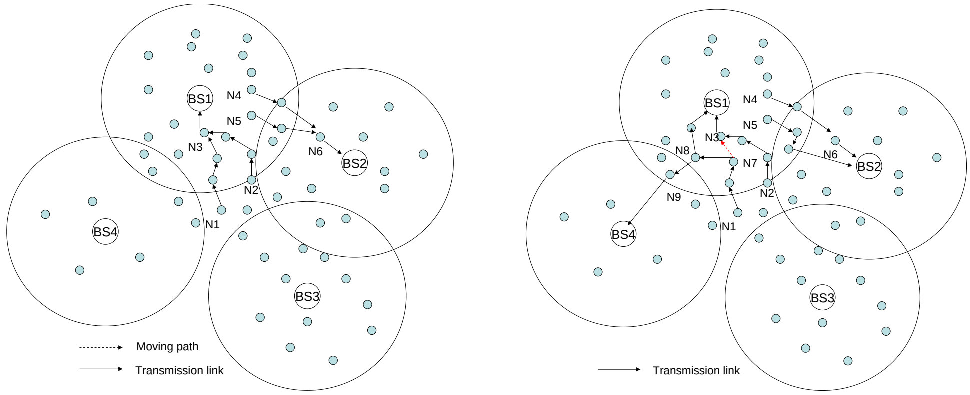
The proposed efficient routing protocol ERP aims to avoid the overloaded mobile gateway nodes, and to increase the communication reliability. Taking advantage of wide-spread mobile nodes bridged by base stations, ERP chooses an ideal mobile gateway node for the message inter-cell transmission to guarantee the reliability and successfulness of the message transmission. In a multi-hop cellular network, a node has a number of neighbors. Each neighbor can be the node that forwards the message to another relay node or base station. To choose a higher capacity node to forward a message can enhance the reliability of data transmission. In ERP, a node chooses a node from its neighbors that has sufficient capacity to reliably forward the data. Buffer storage which is used for storing the message is the basic requirement for data forwarding. Thus, the node first selects the neighbors that have sufficient storage space for the message. It then chooses the neighbor in the options that has the highest channel capacity. However, during the transmission, if the channel conditional decrease sharply or the buffer is nearly congested, the messages can be forwarded to a relay node with higher channel condition and enough buffer size if the TTL of the message still larger than 0. Later, the subsequently messages from other nodes will not go through this node according to the adaptive routing algorithm. Algorithm 1 shows the pseudo-code for the node selection for message forwarding.

Therefore, a node needs to get the current information of its neighbors' storage size and channel capacity to the base station. In ERP protocol, each node periodically updates its channel condition to the base station via beacon messages. The beacon messages are actually sent by the base stations for node identification. Such that a base station can identify the mobile nodes that are in its transmission region. Taking advantage of the beacon messages, each node does not need to send an extra message for the condition of its channel with its base station. Meanwhile, the channel condition information are also periodically exchanged between neighbor mobile nodes through "hello" messages. The "hello" message is originally used for neighbor node identification. Such that, a mobile node can find its neighbor mobile nodes. By piggybacking the channel condition information to the "hello" message, the information exchange does not generate extra overhead.

Each node maintains a neighbor table recording the channel information of its neighbors to the base station. When a source node wants to send messages to the base station, the node checks its neighbor node table to find the best node for message forwarding based on the node selection algorithm. A message has a Time to Live (TTL). Every time when a message go through a node, the TTL of the message will be decreased by one. If the node has the highest channel capacity to the base station, the node will transmit the message to the base station directly. Otherwise, the node chooses a neighbor to forward the message based on the node selection algorithm. No matter whether the node holding the message has the highest channel capacity to the base station or not, if the TTL of the message reaches 0, the node should transmit the messages to the base station directly. This step makes sure that the message can arrive at its destination efficiently without being forwarded always.

Figure 1(a) shows a traditional routing protocol that directly integrates infrastructure routing and ad-hoc routing. If both node $N1$ and node $N2$ want to transmit data stream to a node in another WLAN, they will broadcast the routing query message and find a shortest path to transmit the data to a base station in a multi-hop fashion. In this example, both messages of $N1$ and $N2$ are transmitted through $N3$ before arriving at base station $BS1$, which then forwards the data to the base station of the destination. Therefore, this routing protocol may make the gateway node (i.e $N3$) become overloaded.

Figure 1(b) shows the ERP routing protocol. In ERP, source node $N1$, $N2$ try to transmit messages to the base station. Originally, as Figure 1(a) shows, the messages may be congested at node $N3$. However, after the node $N7$ senses the congestion in the node $N3$, the messages are forwarded to the $N8$ which is the second highest node with good channel to the base station. Such adaptive process will continuous until the messages TTL is reached or the message reach a nodes has the highest channel capacity to the base station in its local region. In the example,



(a) Traditional routing　　(b) ERP

Figure 1. **Routings in multi-hop cellular network**

$N8$ chooses to forward the messages to Base Station 1 or base station 4 via other mobile gateway nodes. With the features of adaptive transmission and short hop path length with short physical distance in each transmission step, ERP significantly decreases the traffic congestion and increases transmission reliability.

4 PERFORMANCE EVALUATION

This section demonstrates the performance of ERP in a multi-hop cellular network through simulation in comparison with AODV for the base station accessing. The simulator is built on ns-2 [27].

The simulated network consists of 50 wireless nodes and 4 base stations unless otherwise indicated. Wireless nodes are randomly deployed around the base stations in a field of 1000×1000 square meters. We used the Distributed Coordination Function (DCF) of IEEE 802.11 as the medium access control layer protocol. The radio transmission range for cellular interface was 250 meters, the ad-hoc interface was 150 meters, and the raw physical link bandwidth was 2Mbits/s. The two-ray propagation model is used for physical layer model. The constant bit rate (CBR) is selected as our traffic mode with traffic as $128k/s$. Source and destination nodes for data transmission were randomly chosen every 10 seconds. The default value of TTL is 2. The buffer threshold is 0.8. The warming time is 50s.

The random way-point mobility model [28] was used to generate the moving direction, the speed and the pause duration of each node. Each node waits for a pause time randomly chosen from $(1-5)$s, then moves to another random position with a speed chosen between 5 to 20m/s.

We assumed that there was no bandwidth and power constraint between the communication of base stations and message can always be transmitted successfully in the infrastructure network. Such an assumption is realistic considering the advanced technologies and hardware in the wired infrastructure networks nowadays.

4.1 SCALABILITY

To evaluate the scalability of ERP and AODV, we measured their throughput in networks with 50 nodes and 20 nodes respectively using the same data transmitting speed. We use “ERP-50” and ”AODV-50” to denote ERP and AODV routing protocols with 50 mobile nodes in the system, respectively. “ERP-20” and ”AODV-20” represent ERP and AODV routings with 20 nodes in the system, respectively. Figure 2 shows that as the number of the mobile nodes increases, the throughput of AODV decreases while the throughput of the ERP remains stable. We can find that ERP produces much higher throughput than AODV. In AODV, more system nodes lead to longer path and more source-destination pairs. Longer path leads to higher probability of message dropping because the path break down. In addition, many messages are congested in the mobile gateway nodes. As a result, many messages are not able to be successfully sent to their destination, leading to less throughput. ERP always chooses the higher-capacity nodes to forward messages, which reduces the probability of message dropping. Therefore, ERP generates much higher throughput than AODV. It can also be observed that the throughput of “AODV-20” decreases at first and then gradually increases. It is because nodes need to discover and maintain routes at first, and later on as the system becomes more stable, the throughput increases. The results illustrate that ERP’s system throughput is stable regardless of network size, but AODV’s throughput decreases as the network size grows. This implies that ERP has higher scalability than AODV.

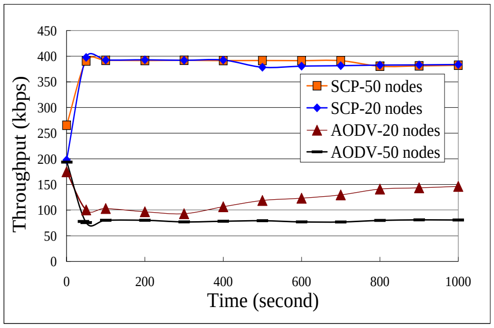


Figure 2. Scalability

4.2 THROUGHPUT CAPACITY

This experiments tested the throughput with different number of source nodes in the network. In the experiment, new source nodes were randomly chosen in every 10 seconds,.

Figure 3 demonstrates the throughput of ERP and AODV versus the number of source nodes. We can observe that the throughput capacity of ERP increases dramatically but that of AODV increases marginally with the growth of source nodes. It is because that in ERP, all message streams are sent to gateway nodes that have sufficient capacity to process the messages promptly. While in AODV, the last relay nodes serving as gateways can easily become bottlenecks due to shortest path transmission feature, leading to high package droppings. In addition, the results demonstrate that ERP produces throughput almost linearly with the number of source nodes. This means that the system throughput of ERP is stable. The reason that the throughput is not completely linear is because that it is inevitable to have some messages dropped during the transmission because of mobile node switching.

4.3 OVERHEAD

We define overhead rate as the number of control message generated per second, and use this metric to evaluate the overhead of ERP and AODV routing protocols. We tested the overhead rate in ERP and AODV versus the number of source nodes. Since the source node consistently generates messages to the nearest base station, the more source nodes in the system means heavier traffic flow.

Figure 4 shows that the overhead rate of AODV is significantly higher than that of ERP as the number of source nodes increases. In addition, the overhead rate of ERP increases almost linearly with the number of source nodes, whereas that of AODV increases sharply as source nodes or source messages grow. It is because the adaptive transmission feature of ERP avoid the packets retransmission

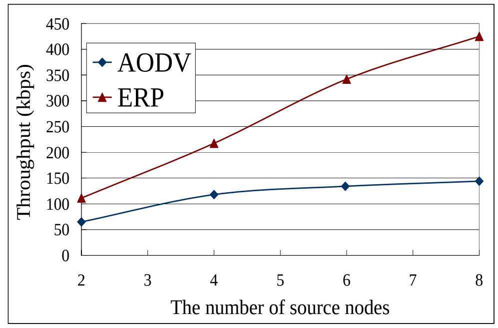


Figure 3. Throughput

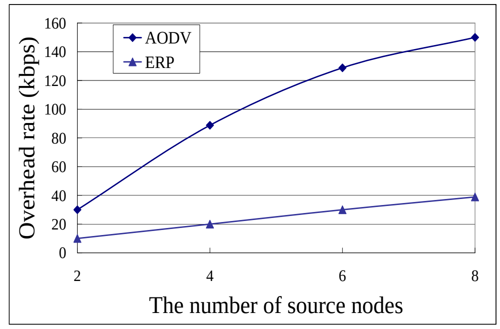


Figure 4. Overhead rate versus number of source node

control overhead and channel contention overhead resulting from the congestion at certain mobile gateway nodes. Thus, the number of control messages is almost proportional to the number of data messages for channel access. However, AODV is prone to the packets congestion at the ceratin gateway nodes. More source nodes in the system make mobile gateway nodes more easily to be congested, leading to data messages droppings and retransmission. In addition, because of the long distance transmission in AODV, the routing path between a source node and a base station is easily to be broken because of the nodes' mobility. Such path breakdown costs a considerable overhead to re-establish a routing path. In contrast, facilitated by TTL, a message in ERP will be forwarded to its destination in a constrained number of nodes, there, ERP is more mobility resilient which further grantees the reliable transmission.

5 CONCLUSIONS

Current multi-hop cellular networks (hybrid wireless networks) which rooted in the multi-hop feature is prone to the network congestion. In this paper, we propose an efficient routing protocol to increase the communication reliability of multi-hop cellular networks. Considering each mobile node has a number of neighbors, and the neighbors have different channel capacity, ERP chooses higher-capacity nodes to forward messages. This helps to make sure that a message is transmitted to its destination reliably. In addition, ERP adaptively determines the number of hops in the routing path. When a node has sufficient channel capacity to forward a message to a base station, it will directly send the message to the base station. Otherwise, it chooses a neighbor node to forward the message. Each message being forwarded has a TTL which decreases every time it is transmitted. When TTL equals to 0, the message is forwarded to the base station directly. This strategy guarantees that a message is sent to its destination efficiently. Simulations results show that ERP can dramatically improve the throughput capacity and reduce congestion of hybrid networks.

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