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An Advanced Multi – Hop Routing Protocol to Extend and Enhance the capacity of Hybrid Wireless Networks

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ABSTRACT

Hybrid wireless networks combining the advantages of both mobile ad-hoc networks and infrastructure wireless networks have been receiving increased attention due to their ultra-high performance. An efficient data routing protocol is important in such networks for high network capacity and scalability. However, most routing protocols for these networks simply combine the ad-hoc transmission mode with the cellular transmission mode, which inherits the drawbacks of ad-hoc transmission. This paper presents a Distributed Three-hop Routing protocol (DTR) for hybrid wireless networks. To take full advantage of the widespread base stations, DTR divides a message data stream into segments and transmits the segments in a distributed manner. It makes full spatial reuse of a system via its high speed ad-hoc interface and alleviates mobile gateway congestion via its cellular interface. Furthermore, sending segments to a number of base stations simultaneously increases throughput and makes full use of widespread base stations. In addition, DTR significantly reduces overhead due to short path lengths and the elimination of route discovery and maintenance. DTR also has a congestion control algorithm to avoid overloading base stations. Theoretical analysis and simulation results show the superiority of DTR in comparison with other routing protocols in terms of throughput capacity, scalability and mobility resilience. The results also show the effectiveness of the congestion control algorithm in balancing the load between base stations.

Key Terms—
Hybrid wireless networks, Routing algorithm, Load balancing, Congestion control

1 INTRODUCTION

Over the past few years, wireless networks including infrastructure wireless networks and mobile ad-hoc networks (MANETs) have attracted significant research interest. The growing desire to increase wireless network capacity for high performance applications has stimulated the development of hybrid wireless networks [1–6]. A hybrid wireless network consists of both an infrastructure wireless network and a mobile ad-hoc network. Wireless devices such as smart-phones, tablets and laptops, have both an infrastructure interface and an adhoc interface. As the number of such devices has been increasing sharply in recent years, a hybrid transmission structure will be widely used in the near future. Such a structure synergistically combines the inherent advantages and overcome the disadvantages of the infrastructure wireless networks and mobile ad-hoc networks. In a mobile ad-hoc network, with the absence of a central control infrastructure, data is routed to its destination through the intermediate nodes in a multi-hop manner. The multi-hop routing needs on-demand route discovery or route maintenance [7–10]. Since the messages are transmitted in wireless channels and through dynamic routing paths, mobile ad-hoc networks are not as reliable as infrastructure wireless networks. Furthermore, because of the multi-hop transmission feature, mobile ad-hoc networks are only suitable for local area data transmission. The infrastructure wireless network (e.g. cellular network) is the major means of wireless communication in our daily lives. It excels at inter-cell communication (i.e., communication between nodes in different cells) and Internet access. It makes possible the support of universal network connectivity and ubiquitous computing _ * Corresponding Author. Email: shenh@clemson.edu; Phone: (864) 656 5931; Fax: (864) 656 5910. _ The authors are with the Department of Electrical and Computer Engineering, Clemson University, Clemson, SC, 29634. E-mail: fshenh, zel, chenxiqg@clemson.edu by integrating all kinds of wireless devices into the network. In an infrastructure network, nodes communicate with each other through base stations (BSes). Because of the long distance one-hop transmission between BSes and mobile nodes, the infrastructure wireless networks can provide higher message transmission reliability and channel access efficiency, but suffer from higher power consumption on mobile nodes and the single point of failure problem [11]. A hybrid wireless network synergistically combines an infrastructure wireless network and a mobile adhoc network to leverage their advantages and overcome their shortcomings, and finally increases the throughput capacity of a wide-area wireless network. A routing protocol is a critical component that affects the throughput capacity of a wireless network in data transmission. Most current routing protocols in hybrid wireless networks [1, 5, 6, 12–18] simply combine the cellular transmission mode (i.e. BS transmission mode) in infrastructure wireless networks and the ad-hoc transmission mode in mobile ad-hoc networks [8, 9, 7]. That is, as shown in Figure 1 (a), the protocols use the multi-hop routing to forward a message to the mobile gateway nodes that are closest to the BSes or have the highest bandwidth to the BSes. The bandwidth of a channel is the maximum throughput (i.e., transmission rate in bits/s) that can be achieved. The mobile gateway nodes then forward the messages to the BSes, functioning as bridges to connect the ad-hoc network and the infrastructure network. However, direct combination of the two transmission modes inherits the following problems that are rooted in the ad-hoc transmission mode. _ High overhead. Route discovery and maintenance incur high overhead. The wireless random access medium access control (MAC) required in mobile ad-hoc networks, which utilizes control handshaking and a backoff mechanism, further increases overhead.

_ Hot spots. The mobile gateway nodes can easily become hot spots. The RTS-CTS random access, in which most traffic goes through the same gateway, and the flooding employed in mobile ad-hoc routing to discover routes

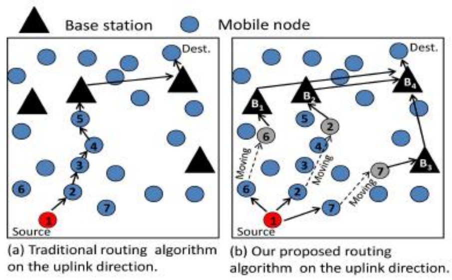


Fig. 1: Traditional and proposed routing algorithms on the uplink direction.

may exacerbate the hot spot problem. In addition, mobile nodes only use the channel resources in their route direction, which may generate hot spots while leave resources in other directions under-utilized. Hot spots lead to low transmission rates, severe network congestion, and high data dropping rates.Low reliability. Dynamic and long routing paths lead to unreliable routing. Noise interference and neighbor interference during the multi-hop transmission process cause a high data drop rate. Long routing paths increase the probability of the occurrence of path breakdown due to the highly dynamic nature of wireless ad-hoc networks. These problems become an obstacle in achieving high throughput capacity and scalability in hybrid wireless networks. Considering the widespread BSes, the mobile nodes have a high probability of encountering a BS while moving. Taking advantage of this feature, we propose a Distributed Three-hop Data Routing protocol (DTR). In DTR, as shown in Figure 1 (b), a source node divides a message stream into a number of segments. Each segment is sent to a neighbor mobile node. Based on the QoS requirement, these mobile relay nodes choose between direct transmission or relay transmission to the BS. In relay transmission, a segment is forwarded to another mobile node with higher capacity to a BS than the current node. In direct transmission, a segment is directly forwarded to a BS. In the infrastructure, the segments are rearranged in their original order and sent to the destination. The number of routing hops in DTR is confined to three, including at most two hops in the ad-hoc transmission mode and one hop in the cellular transmission mode. To overcome the aforementioned shortcomings, DTR tries to limit the number of hops. The first hop forwarding distributes the segments of a message in different directions to fully utilize the resources, and the possible second hop forwarding ensures the high capacity of the forwarder. DTR also has a congestion control algorithm to balance the traffic load between the nearby BSes in order to avoid traffic congestion at BSes. Using self-adaptive and distributed routing with highspeed and short-path ad-hoc transmission, DTR significantly increases the throughput capacity and scalability of hybrid wireless networks by overcoming the three shortcomings of the previous routing algorithms. It has the following features: _ Low overhead. It eliminates overhead caused by route discovery and maintenance in the ad-hoc transmission mode, especially in a dynamic environment. _ Hot spot reduction. It alleviates traffic congestion at mobile gateway nodes while makes full use of channel resources through a distributed multi-path relay. _ High reliability. Because of its small hop path length with a short physical distance in each step, it alleviates noise and neighbor interference and avoids the adverse effect of route breakdown during data transmission. Thus, it reduces the packet drop rate and makes full use of spacial reuse, in which several source and destination nodes can communicate simultaneously without interference. The rest of this paper is organized as follows. Section 2 presents a review of representative hybrid wireless networks and multi-hop routing protocols. Section 3 details the DTR protocol, with an emphasis on its routing methods, segment structure, and BS congestion control. Section 4 theoretically analyzes the performance of the DTR protocol. Section 5 shows the performance of the DTR protocol in comparison to other routing protocols. Finally, Section 6 concludes the paper.

2 RELATED WORK

1) Ucan: A Unified Cell and Ad-hoc Network architecture [2].This paper presents a Unified Cellular and Ad-hoc Network (UCAN) structure to increase cell throughput. In UCAN, a mobile client hasIEEE 802.11 based peer topeer linksand3G cellular link. The 3G cellularbase stations distribute packets to destination station with low channel quality to proxy clients. The proxy clients use an Ad-Hoc network made up of other mobile clients and IEEE 802.11 wireless links to distribute the packets to the destinations station. This paper further represents secure relayed packets for other stations.

Extensive simulation with IEEE 802.11(b). We show that the UCAN architecture can gives separate user's output by up to 80% and the aggregate throughput of downlink by up to 60%

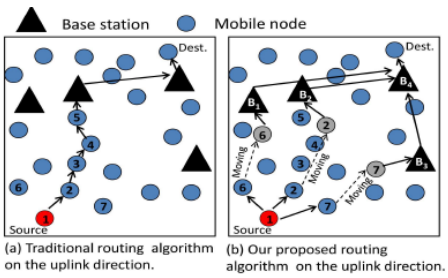
2) Multi-hop cellular: This is new architecture for wireless communications [3], this paper represents a new architecture, Multihop Cellular Network (MCN) for wireless communication. MCN reserves the advantage of conventional single hop cellular network (SCN), where the service infrastructure is designed by fix bases and it also the flexible of ad-hoc networks, where wireless transmission through mobile stations in Multiple Hops are allowed. The MCN can be reducing the required number of bases to enhance the throughput performance while limiting path encountered in ad-hoc networks. In addition SCN and MCN are analyzed; in term of mean hop count, hop by hop throughput and end throughput, and mean number of channels under different.

3) Connectivity in ad hoc and hybrid networks [4].This paper shows the introduction of a sparse network of base station do significantly help in increase the connectivity, but it only when the node density is much more in one dimension than in the other. They explain the results by percolation theory. This paper obtains analysis of expressions of connectivity in the 1- dimension case. They also show that at a less spatial density of nodes and bottleneck are unavoidable; results obtained on real population data confirm our finding.

4) Highly Dynamic Destination Sequenced Distance Vector routing (DSDV) for mobile computers. [5] In this paper they represented a new structure for the operation of such ad-hoc network. The basic invention of the structure is to operate every mobile host as a special router, which eventually advertising its views of the interconnection topology with another mobile hosts within the networks. That amounts to sort of routing protocol. They have investigation modified to the Bellman Ford routing mechanisms, as specific to make it compatible for dynamic and self-starting network mechanism as is required by users to utilize ad-hoc networks. It modifications address some of the objections to the use of Bellman-Ford, related to the less looping properties of algorithms in the face of broke links and the results time depends upon nature of the interconnection topology describing the link between the mobile hosts. They describe the ways in which the network layer routing can be modified to provide MAC layer support for Ad-hoc networks.

5) Ad-hoc On Demand Distance Vector (AODV) routing[6], In this paper they represent AODV algorithm for the operation of Ad-hoc networks to every mobile host operates as a some special router, and routes are obtained as need with small or no reliance on advertisements their new routing algorithm is more suitable for a dynamic self-starting network, as required by users wishing to utilize ad-hoc networks AODV provides loop routes even while repairs broken links Because the protocol do not require global routing advertisements, the demand on the bandwidth available to the mobile nodes is less than in those protocols that do necessary such advertisements. We can maintain the advantages of basic distance vector routing mechanisms in network. They show that their algorithm scales to larger populations of mobile nodes to form Ad-hoc networks it also include an evaluation methodology and simulation results to the operation of algorithm Keywords.

A hybrid wireless network synergistically combines an infrastructure wireless network and a mobile adhoc network to leverage their advantages and overcometheir shortcomings, and finally increases throughput capacity of a wide-area wireless network. A routing protocol is a critical component that affects the throughput capacity of a wireless network in data transmission. Most current routing protocols in hybrid wireless networks [1, 5, 6, 12–18] simply combine the cellular transmission mode (i.e. BS transmission mode) in infrastructure wireless networks and the ad-hoc transmission mode in mobile ad-hoc networks [8, 9, 7]. That is, as shown in Figure 1 (a), the protocols use the multi-hop routing to forward a message to the mobile gateway nodes that are closest to the BSes or have the highest bandwidth to the BSes. The bandwidth of a channel is the maximum throughput (i.e., transmission rate in bits/s) that can be achieved. The mobile gateway nodes then forward the messages to the BSes, functioning as bridges to connect the ad-hoc network and the infrastructure network. However, direct combination of the two transmission modes inherits the following problems that are rooted in the ad-hoc transmission mode. _ High overhead. Route discovery and maintenance incur high overhead. The wireless random access medium access control (MAC) required in mobile ad-hoc networks, which utilizes control handshaking and a backoff mechanism, further increases overhead. _ Hot spots. The mobile gateway nodes can easily become hot spots. The RTS-CTS random access, in which most traffic goes through the same gateway, and the flooding employed in mobile ad-hoc routing to discover routes



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may exacerbate the hot spot problem. In addition, mobile nodes only use the channel resources in their route direction, which may generate hot spots while leave resources in other directions under-utilized. Hot spots lead to low transmission rates, severe network congestion, and high data dropping rates. _ Low reliability. Dynamic and long routing paths lead to unreliable routing. Noise interference and neighbor interference during the multi-hop transmission process cause a high data drop rate. Long routing paths increase the probability of the occurrence of path breakdown due to the highly dynamic nature of wireless ad-hoc networks. These problems become an obstacle in achieving high throughput capacity and scalability in hybrid wireless networks. Considering the widespread BSes, the mobile nodes have a high probability of encountering a BS while moving. Taking advantage of this feature, we propose a Distributed Three-hop Data Routing protocol (DTR). In DTR, as shown in Figure 1 (b), a source node divides a message stream into a number of segments. Each segment is sent to a neighbor mobile node. Based on the QoS requirement, these mobile relay nodes choose between direct transmission or relay transmission to the BS. In relay transmission, a segment is forwarded to another mobile node with higher capacity to a BS than the current node. In direct transmission, a segment is directly forwarded to a BS. In the infrastructure, the segments are rearranged in their original order and sent to the destination. The number of routing hops in DTR is confined to three, including at most two hops in the ad-hoc transmission mode and one hop in the cellular transmission mode. To overcome the aforementioned shortcomings, DTR tries to limit the number of hops. The first hop forwarding distributes the segments of a message in different directions to fully utilize the resources, and the possible second hop forwarding ensures the high capacity of the forwarder. DTR also has a congestion control algorithm to balance the traffic load between the nearby BSes in order to avoid traffic congestion at BSes. Using self-adaptive and distributed routing with highspeed and short-path ad-hoc transmission, DTR significantly increases the throughput capacity and scalability of hybrid wireless networks by overcoming the three shortcomings of the previous routing algorithms. It has the following features: _ Low overhead. It eliminates overhead caused by route discovery and maintenance in the ad-hoc transmission mode, especially in a dynamic environment. _ Hot spot reduction. It alleviates traffic congestion at mobile gateway nodes while makes full use of channel resources through a distributed multi-path relay. _ High reliability. Because of its small hop path length with a short physical distance in each step, it alleviates noise and neighbor interference and avoids the adverse effect of route breakdown during data transmission. Thus, it reduces the packet drop rate and makes full use of spacial reuse, in which several source and destination nodes can communicate simultaneously without interference. The rest of this paper is organized as follows. Section 2 presents a review of representative hybrid wireless networks and multi-hop routing protocols. Section 3 details the DTR protocol, with an emphasis on its routing methods, segment structure, and BS congestion control. Section 4 theoretically analyzes the performance of the DTR protocol. Section 5 shows the performance of the DTR protocol in comparison to other routing protocols. Finally, Section 6 concludes the paper.

2 RELATED WORK

In order to increase the capacity of hybrid wireless networks, various routing methods with different features have been proposed. One group of routing methods integrate the ad-hoc transmission mode and the cellular transmission mode [1, 5, 6, 14, 16–18]. Dousse et al. [6] built a Poisson Boolean model to study how a BS increases the capacity of a MANET. Lin et al. [5] proposed a Multihop Cellular Network and derived its throughput. Hsieh et al. [14] investigated a hybrid IEEE 802.11 network architecture with both a distributed coordination function and a point coordination function. Luo et al. [1] proposed a unified cellular and ad-hoc network architecture for wireless communication. Cho et al. [16] studied the impact of concurrent transmission in a downlink direction (i.e. from BSes to mobile nodes) on the system capacity of a hybrid wireless network. In [17, 18], a node initially communicates with other nodes using an ad-hoc transmission mode, and switches to a cellular transmission mode when its performance is better than the ad-hoc transmission. The above methods are only used to assist intra-cell ad-hoc transmission rather than inter-cell transmission. In inter-cell transmission [1, 5, 6], a message is forwarded via the ad-hoc interface to the gateway mobile node that is closest to or has the highest uplink transmission bandwidth to a BS. The gateway mobile node then forwards the message to the BS using the cellular interface. However, most of these routing protocols simply combine routing schemes in ad-hoc networks and infrastructure networks, hence inherit the drawbacks of the ad-hoc transmission mode as explained previously. DTR is similar to the Two-hop transmission protocol [19] in terms of the elimination of route maintenance and the limited number of hops in routing. In Two-hop, when a node's bandwidth to a BS is larger than that of each neighbor, it directly sends a message to the BS. Otherwise, it chooses a neighbor with a higher channel and sends a message to it, which further forwards the message to the BS. DTR is different from Two-hop in three aspects. First, Two-hop only considers the node transmission within a single cell, while DTR can also deal with inter-cell transmission, which is more challenging and more common than intra-cell communication in the real world. Second, DTR uses distributed transmission involving multiple cells, which makes full use of system resources and dynamically balances the traffic load between neighboring cells. In contrast, Two-hop employs single-path transmission.

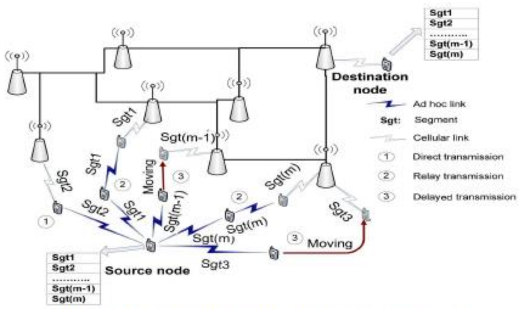

Fig. 2: Data transmission in the DTR protocol.

3 DISTRIBUTED THREE-HOP ROUTING PROTOCOL

3.1 Assumption and Overview

Since BSes are connected with a wired backbone, we assume that there are no bandwidth and power constraintson transmissions between BSes. We use intermediate nodes to denote relay nodes that function as gateways connecting an infrastructure wireless network and a mobile ad-hoc network.We assume every mobile node is dual-mode; that is, it has ad-hoc network interface such as a WLAN radio interface and infrastructure network interface such as a 3G cellular interface. DTR aims to shift the routing burden from the adhoc network to the infrastructure network by taking advantage of widespread base stations in a hybrid wireless network. Rather than using one multi-hop path to forward a message to one BS, DTR uses at most two hops to relay the segments of a message to different BSes in a distributed manner, and relies on BSes to combine the segments. Figure 2 demonstrates the process of DTR in a hybrid wireless network. We simplify the routings in the infrastructure network for clarity. As shown in the figure, when a source node wants to transmit a message stream to a destination node, it divides the message stream into a number of partial streams called segments and transmits each segment to a neighbor node. Upon receiving a segment from the source node, a neighbor node locally decides between direct transmission and relay transmission based on the QoS requirement of the application. The neighbor nodes forward these segments in a distributed manner to nearby BSes. Relying on the infrastructure network routing, the BSes further transmit the segments to the BS where the destination node resides. The final BS rearranges the segments into the original order and forwards the segments to the destination. It uses the cellular IP transmission method [30] to send segments to the destination if the destination moves to another BS during segment transmission. Our DTR algorithm avoids the shortcomings of adhoc transmission in the previous routing algorithms that directly combine an ad-hoc transmission mode and a cellular transmission mode. Rather than using the multihop ad-hoc transmission, DTR uses two hop forwarding by relying on node movement and widespread base stations. All other aspects remain the same as those in the previous routing algorithms (including the interaction with the TCP layer). DTR works on the Internet layer. It receives packets from the TCP layer and routes it to the destination node, where DTR forwards the packet to the TCP layer. The data routing process in DTR can be divided into two steps: uplink from a source node to the first BS and downlink from the final BS to the data's destination. Critical problems that need to be solved include how a source node or relay node chooses nodes for efficient segment forwarding, and how to ensure that the final BS sends segments in the right order so that a destination node receives the correct data. Also, since traffic is not evenly distributed in the network, how to avoid overloading BSes is another problem. Below, Section 3.2 will present the details for forwarding node selection in uplink transmission and Section 3.3 will present the segment structure that helps ensure the correct final order of segments in a message, and DTR's strategy for downlink transmission. Section 3.4 will present the congestion control algorithm for balancing a load between BSes.

4 PERFORMANCE EVALUATION

This section demonstrates the properties of DTR through simulations on NS-2 [36] in comparison to DHybrid [17], Two-hop [19] and AODV [8]. In DHybrid, a node firstuses broadcasting to observe a multi-hop path to its own BS and then forwards a message in the ad-hoc transmission mode along the path. During the routing process, if the transmission rate (i.e., bandwidth) of the next hop to the BS is lower than a threshold, rather than forwarding the message to the neighbor, the node forwards the message directly to its BS. The source node will be notified if an established path is broken during data transmission. If a source sends a message to the same destination next time, it uses the previously established path if it is not broken. In the Two-hop protocol, a source node selects the better transmission mode between direct transmission and relay transmission. If the source node can find a neighbor that has higher bandwidth to the

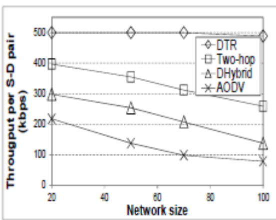

Fig. 6: Throughput vs. network size (simulation).

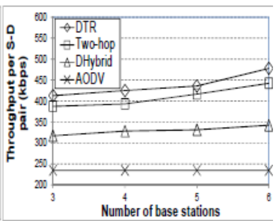

Fig. 7: Throughput vs. numbe of BSes.

BS than itself, it transmits the message to the neighbor. Otherwise, it directly transmits the message to the BS. Unless otherwise specified, the simulated network consists of 50 mobile nodes and 4 BSes. In the ad-hoc component of the hybrid wireless network, mobile nodes are randomly deployed around the BSes in a field of 1000_1000 square meters.We used the Distributed Coordination Function (DCF) of the IEEE 802:11 as the MAC layer protocol. The transmission range of the cellular interface was set to 250 meters, and the raw physical link bandwidth was set to 2Mbits/s. The transmission power of the ad-hoc interface was set to the minimum value required to keep the network connected for most times, even when nodes are in motion in the network. Then, the influence of the transmission range on different methods' performance is controlled. Specifically, we set the transmission range through the ad-hoc interface to 1.5 times of the average distance between neighboring nodes, which can be obtained by measuring the simulated network. We used the two-ray propagation model for the physical layer model. Constant bit rate (CBR) was selected as the traffic mode in the experiment with a rate of 640kbps. In the experiment, we randomly chose 4 source nodes to continuously send messages to randomly chosen destination nodes. The number of channels for each BS was set to 10. We set the number of redundant routing paths b in Section 3.4 to 1. We assumed that therewas no capacity degradation during transmission between BSes. This assumption is realistic considering the advanced technologies and hardware presently used in wired infrastructure networks. There was no message retransmission for failed transmissions in the experiments. We employed the random way-point mobility model [37] to generate the moving direction, speed, and pause duration of each node. In this model, each node moves to a random position with a speed randomly chosen from (1□20)m/s. The pause time of each node was set to 0.

We set the number of segments of a message to the connection degree of the source node. The simulation warmup time was set to 100s and the simulation time was set to 1000s. We conducted the experiments 5 times and used the average value as the final experimental result. To make the methods comparable, we did not use the congestion control algorithm in DTR unless otherwise indicated.

6 CONCLUSIONS

Hybrid wireless networks have been receiving increasing attention in recent years. A hybrid wireless network combining an infrastructure wireless network and a mobile ad-hoc network leverages their advantages to increase the throughput capacity of the system. However,current hybrid wireless networks simply combine the routing protocols in the two types of networks for IEEE Transactions on Mobile Computing,Volume:PP,Issue:99,Date of Publication :08.January.2015 data transmission, which prevents them from achievinghigher system capacity. In this paper, we propose a Distributed Three-hop Routing (DTR) data routing protocol that integrates the dual features of hybrid wireless networks in the data transmission process. In DTR, a source node divides a message stream into segments and transmits them to its mobile neighbors, which further forward the segments to their destination through an infrastructure network. DTR limits the routing pathlength to three, and always arranges for high-capacity nodes to forward data. Unlike most existing routing protocols, DTR produces significantly lower overhead by eliminating route discovery and maintenance. Inaddition, its distinguishing characteristics of short path length, short-distance transmission, and balanced load distribution provide high routing reliability and efficiency. DTR also has a congestion control algorithm to avoid load congestion in BSes in the case of unbalanced traffic distributions in networks. Theoretical analysis and simulation results show that DTR can dramatically improve the throughput capacity and scalability of hybrid wireless networks due to its high scalability, efficiency, and reliability and low overhead.

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