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A Smart Collaborative Routing Protocol for QoE Enhancement in Multi-Hop Wireless Networks

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ABSTRACT The multi-hop wireless network (MWN) is an important green communication method for the Internet of Things (IoT). However, existing routing protocols in MWN have insufficient considerations for quality of experience (QoE). In this paper, we propose a QoE enhancement routing (QER) protocol based on smart collaborative theory. First, crucial parameters which affect data transmission process are analyzed comprehensively and applications of MWN are introduced. Second, two stages of QER protocol, i.e. collaborative perception and smart decision, are designed to collect real-time network information and decide the optimal routing mechanism, respectively. Corresponding procedures are discussed in-depth with the system availability. Third, we integrate three routing mechanisms into QER and conduct a comparative analysis. Evaluation environments are created with reasonable configurations. Performance validation demonstrates that our solution is able to intelligently execute the suitable strategy. Compared with traditional protocols, QER can outperform other candidates in diverse scenarios.

INDEX TERMS Smart collaborative, adaptive routing, quality of experience, multi-hop network.

I. INTRODUCTION

Internet of Things (IoT) is a technological revolution which can promote the world development and human progress [1]. With emerging wireless network system such as 5G cellular network [2] and 802.11ax [3], IoT is expected to connect anyone or anything anytime based on heterogeneous communication approaches [4]–[6]. In fact, the IoT is a generic concept which has been extended to multiple fields. For industrial IoT, it is significant to find a way to increase network reliability and capacity [7]. Opportunities in transportation IoT are investigated to propose high-speed mobile network for railway [8], [9]. Researchers dedicated to ubiquitous power IoT are more concerned about the accurate positioning [10], billing issues [11] and deployment optimization [12]. Moreover, secure IoT includes attack defense [13], authentication [14] and data privacy are discussed via different perspectives. Together with these achievements, the importance of networking patterns are gradually witnessed and widely recognized in last decade.

Multi-hop wireless networks (MWN), as a classic paradigm in IoT, have become a hot topic. As shown in Fig.1, several application scenarios for MWN are presented. Generally, MWN are mainly used on the edge. It enables direct communication among adjacent devices to provide flexible and efficient services. Firstly, diverse user devices in neighbor area can send any data to each other directly through MWN. This can decrease transmit delay and access burden obviously. A typical example is device to device communication (D2D) in 5G network. Secondly, when a large amount of sensor data needs to be transmitted to a remote server, the access network will bear a huge impact. Deploying MWN to aggregate and process data locally will effectively reduce the difficulty of connecting massive terminals. This is a significant project in emerging Industrial Internet of Things (IIoT). Thirdly, networkable vehicle will turn to the main travel tool in the future. Vehicle communication not only needs to transmit control message, but also delivery various traffic to support the intelligent transportation. According to above discussion, it is easy to conclude that MWN are the promising component of IoT applications such as high-capacity access network, industry network, and smart cities. Since many-to-one access mode of traditional Internet, access network

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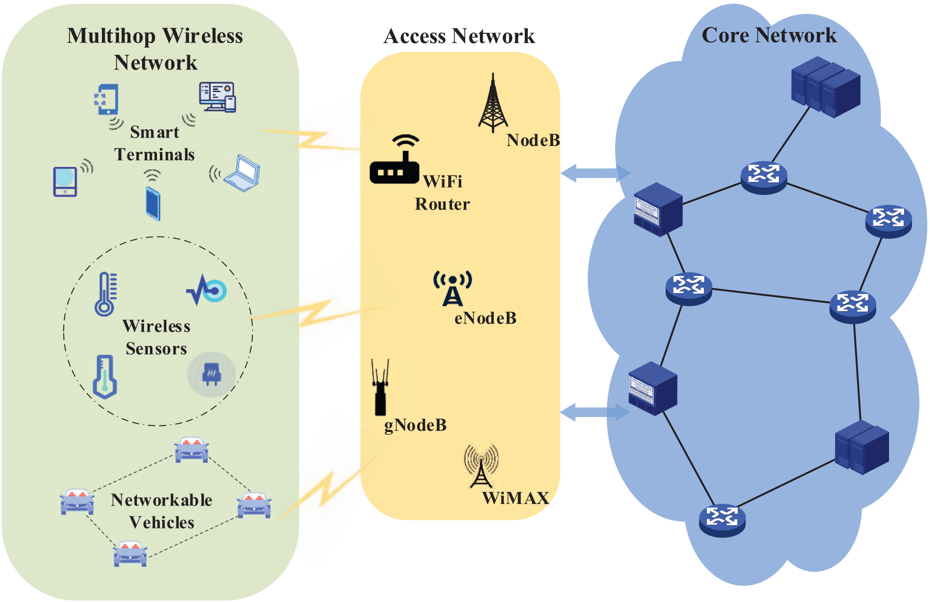


FIGURE 1. **Application scenarios of MWN.**

can be relieved and carbon emissions will decreased through adopting MWN suitably [15], [16]. On condition that reasonable routing mechanism is adopted in wireless terminals, total energy consumption can be reduced evidently. Hence, MWN can be regarded as a proper green network method. However, there are still many challenges during the implementation of MWN. One of the essential problems is the way to discovery the reliable routes that satisfy the user experience.

Traditional routing protocols in MWN can be classified into three categories: reactive, proactive, and hybrid [17]. Reactive routing protocols, like AODV [18] and DSR [19], can tolerate highly dynamic scenarios since routes are only generated when the source node need. Proactive routing protocols like OLSR [20] periodically maintain routing tables containing each node. They have been applied in low mobility scenes and demonstrate optimal latency performance. Hybrid routing protocols like ZRP [21] are supposed to construct large-scale network as a consequence of integrating aforementioned two kinds of protocols. Furthermore, some scholars have proposed solutions to improve the data delivery based on positioning method [22], [23]. Above protocols focus on principle of routing mechanism in specific backgrounds. It is worth noting that the MWN provides transmission interfaces for various services which have own quality of experience (QoE) requirements. Unfortunately, satisfying all kinds of services in MWN is a critical and sophisticated problem due to spatiotemporal changes of terminals. For example, higher moving speed of terminals often lead to more packet loss incidents and higher network load may cause more congestion.

However, existing protocols cannot guarantee QoE of different users. Motivated by solving such complex problems, we proposed a QoE enhancement routing (QER) protocol to provide flexible routing options. In QER protocol, terminals exchange the real-time state periodically and collaboratively generate the summary information of current network. Once the summary information is obtained, nodes can automatically determine the most suitable routing mechanism based on machine learning technology. The contributions of this work include:

1) We design several calculation models to measure network states and a novel multi-service oriented protocol is illustrated in detail.

2) Diverse routing mechanisms are integrated in our solutions to enable intelligent routing, corresponding experiment and evaluation are also provided.

The rest of this paper is organized as follows: Section II introduces adopted assumptions and formulations. Section III describes the collaborative perception and smart decision of the QER protocol. Related routing mechanisms are introduced in Section IV. Section V show numerical results through simulation. Finally, related work and conclusion are respectively presented in Section VI and VII.

II. SYSTEM MODEL

In this section, we display our analysis and assumptions of MWN and firstly. Then we elaborated on key parameters which are highly related to network quality, including the number of nodes, relative speed, link change rate, and average network load. It should be noted that in this paper, we use the terms ‘node’ and ‘terminal’ interchangeably.

A. PRELIMINARY ANALYSIS

It is envisioned that emerging IoT will carry considerable traffic. As a important component of IoT, MWN can offload lots of traffic, which is transmitting in core network now, to the edge network. The significance of MWN is to deliver data directly for neighboring devices, it is probably to save the electric energy, lighten the pressure on infrastructure, and reduce transmission delay. Generally, there is no central entity to organize or controll the network since all nodes in MWN are peer entities.

Mobile terminals construct a highly dynamic network. Network state affect user experience deeply and main factors can be divided into two aspects: on the one hand, terminals which are in charge of data delivery can move at any movement. Such a high-risk architecture means more packet loss. On the other hand, as the amount of nodes participating in the network increases, the transmission delay augments non-linearly due to limited network resources.

In order to improve the quality of user experience, we focused on the relationship between network state and its performance. For simplicity in this paper, we assume nodes in MWN have uniform capability and communicable interfaces(e.g. WiFi Direct [24]). When a source node expect to transmit data, other nodes assist in routing and forwarding without protest. Nodes are assumed to access network through contention-based technology (e.g. CSMA/CD) so that the transmission performance will be impacted by any node running in the same band.

In addition, we classify demand of QoE into three categories: Minimal Energy Consumption, Maximum Arrive Rate, and Minimal Average Delay. These requirements are correspond to several typical services. For example, terminals hope to reduce the energy consumption to prolong service time in green communication or emergency communication; When users plan to transmit large files, high arrive rate brings shorter transmission time and better user experience; When users need real-time applications, delay is the most crucial indicator. Above all, necessary formulations about the way to quantify network state are introduced in the next subsection.

B. RELEVANT FORMULATIONS

Obviously, the level of node mobility is the decisive factor because it is closely related with link break. Further, valuable hardware resources will be exhausted as the the increase of nodes and load. Hence, variables such as nodes mobility, node quantity, and network load make a huge impact on user experience. For the purpose of evaluating these variables, we use the following formulas to characterize each of them. In our proposed scheme, nodes are required to calculate above parameters collaboratively.

1) NODE AMOUNT

First of all, nodes have to be aware of the quantity of alive nodes. Due to the decentralized architecture, terminals have to count the total number of existing nodes through interacting with each other periodically. Hence, we designed a collaborative perception scheme and the details will be introduced in the next section. In brief, this scheme divides the network topology into multiple regions, each with a unique domain manager. Managers collect network state information to compute the node quantity N as follow:

$$N = \sum_{i=1}^{k} N_i \tag{1}$$

k is the number of domain and N_i represents the number of nodes of domain i.

In this paper, we adopt relative speed and link change rate, which are popular features, to represent mobility level.

2) AVERAGE RELATIVE SPEED

In order to count the overall mobility level, nodes should acquire the average relative moving speed among adjacent nodes. The relative speed at time t between node i and node j is defined as:

$$V(i,j,t) = \frac{\left|d_{t-t_p} - d_t\right|}{t_p} \tag{2}$$

where t_p is the preset time period, d is the distance from i to j. Terminals need to measure distance in advance. We considered the received signal strength indicator (RSSI) based range method, this method is promise to be widely used in the IoT since its low energy cost and implementation requirements. RSSI based methods are according to the famous Friis equation. It correlate the distance d between nodes and the RSSI in the packet through:

$$r = P_{\text{ref}} - 10n\log_{10} d \tag{3}$$

where P_{ref} is premeasured received power value at a distance of 1 meter from the sender, n is the system loss coefficient that depends on the wireless propagation model. Taking a typical model TwoRayGround as an example, it considers radio wave transmitting directly or reflectively. Under this model, r can be expressed as:

$$r = \begin{cases} P_{\text{ref}} - 20\log_{10} d & d \le 4\pi h_t h_r/\lambda \\ P_{\text{ref}} - 40\log_{10} d & d > 4\pi h_t h_r/\lambda \end{cases} \tag{4}$$

noted that h is the antenna height and λ is the wavelength. A node can combine equations (2) and (4) to caculate the relative speed of the packet sender. Then the average global relative speed for P pairs of nodes within one hop can be calculated through:

$$\bar{V} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} V(i,j,t)}{P} \tag{5}$$

3) AVERAGE LINK CHANGE RATE

Due to the geographical limitation, link failures often occur even though node move slowly. Therefore, periodic statistics of link change rates are necessary to indicate mobility level. The average link change rate is defined as:

$$\overline{R} = \frac{\sum_{i=1}^{N} Ci}{N} \tag{6}$$

C_i is a counter of that increases by one whenever a node add or remove an entry in Neighbor List and it should be reset to 0 periodically.

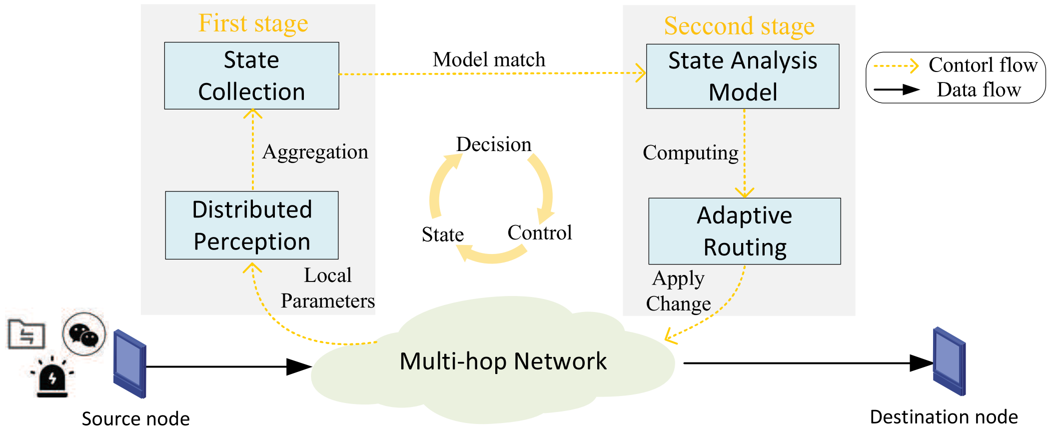


FIGURE 2. **QER structure.**

4) Network Load:When the network load become excess, packets are likely to be dropped because of bandwidth or insufficient buffer queue. The the buffer useage Bi can reflect the traffic passed through node i. And the average utilization of receive buffer as:

$$\overline{B} = \frac{\sum_{i=1}^{N} Bi}{N} \tag{7}$$

In this section, we briefly introduce the MWN and our assumptions. Several key variables are given to represent the network status. Next, we will explain the principle of proposed adaptive routing solution in detail.

III. QER PROTOCOL DESIGN

As discussed in the section I, the network performance is closely related to network status and adopted routing mechanism. Therefore, some adaptive routing protocols were proposed to switch routing approaches in various scenarios. In such protocols, nodes adjust the routing mechanism based on real-time some network state. Due to the lack of centralized management facilities in multi-hop networks, it is difficult for nodes to obtain the fine-grained network status and make the right decision. However, the smart collaborative theory [25] can guide nodes to find the suitable routing mechanism with coarse-grained network parameters.

In this section, we introduced the idea of quality of experience enhancement routing (QER) proposal: a flexible adaptive protocol consists of two stages: collaborative perception and smart decision. Fig.2 present the architecture of QER. The key issue of QER is to collect network information based on a distributed sensing strategy firstly and then find the optimal routing method to meet the requirements of the service based on the trained machine learing model.

A. *FIRST STAGE: COLLABORATIVE PERCEPTION*

Traditionally, fine-grained network monitoring for multi-hop wireless network is almost impossible. However, a terminal can send a HELLO message to obtain the coarse-grained information of its neighbors such as the estimated relative speed or traffic load. Specific sink nodes (managers) can generate a brief status report of the whole network through information integration. Benefit from this idea, we design a domain-based collaborative perception scheme. The main procedures include domain generation, manager selection, and inter-domain interaction. The detailed process of nodes in the collaborative perception is shown in Fig.3. All nodes will periodically broadcast HELLO messages with a lifetime set to one hop, and managers will periodically multicast inter-domain messages to other managers. Existing nodes keep listening for HELLO messages. When a node receives one, it will estimate the distance to the peer node and update relevant items in the neighbor list according to the message. Moreover, node chooses a certain behavior such as forwarding, updating, or ignoring based on its roles when an inter-domain message arrived.

Pseudo code 1: Collaborative Perception

```
Set broadcast timer $t_p$, interexchange timer $t_i$
while node $i$ is available:
  keep listening;
  if $i$ receive a HELLO packet from $j$:
     calculate relative speed with $j$ and update Neighbor List
  if $i$ receive an interdomain packet from $k$:
     if $i$ is manager:
        update the Domain List
     else if $i$ is gateway:
        forward packet to other connected managers
  while $t_p = 0$ do:
     broadcast HELLO packet
  end while
  if $i$ is manager:
     while $t_i = 0$ do:
        multicast interdomain packet
     end while
  end if
end while
```

FIGURE 3. **Pseudo codes of collaborative perception.**

In fact, domain is a concept like the cluster in hierarchical routing protocols. However, the main purpose of domain establishment in our protocol is to perceive network state rather than optimize routing. In order to set up domains, the first concern of nodes is how to find their neighbors. In this paper, we refer to this stage as collaborative perception: all nodes compulsively flood HELLO packets periodically and the maximum propagation range of these packets is one hop. The packet format is shown in Fig.4 and every node will maintain a Neighbor List and keeps the crucial information about their neighbors. The Neighbor List entry also contains a valid time item to indicate its freshnes. Each entry will be deleted when valid time become zero. Obviously, the information maintained by nodes is scalable, such as relative speed, receive buffer depth, and residual energy, etc. A node will check the Neighbor List whenever a HELLO packet is receiving. If the source IP address of the packet have not be stored in the Neighbor List, a new entry will be inserted. Otherwise, the content of corresponding entry will be updated according to HELLO packet. Hence, scattered nodes are associated through periodic interactions and the next step is to select domain managers reasonably.

The main job of the domain manager is to collect the network status for decision-making through collaboration. Compared to broadcast-based network awareness strategies, this will reduce redundant data transmission. Certain nodes will turn into domain managers while the network is under construction or previous managers are disappeared. A node which does not join in a domain need to judge whether a manager is already existed by inspecting received HELLO packets firstly. Since the "IP address" field in the HELLO message sent by the manager is the same as the "Domain" field, a node will apply to join the corresponding domain once it receives such a message. If the node does not receive a message from the manager after two broadcast intervals, the manager generation process will be started. A distributed manager election process in our solution is as following:

1.When there is no manager existing, each node will check their Neighbor List to find an entity with the most neighbors. Such entities will be elected as domain managers.

2.In case of multiple nodes qualify the above requirement, the node owns the lowest average relative speed will become manager. Because the lower the relative speed, the more stable the link between a node and its neighbors.

3. The election of managers is a continuous task. Manager is considered unique in a domain, so election will be restarted if multiple managers get together.

As shown in Fig.5, node A has the most neighbors in its surrounding area, so it becomes a domain manager. Node B receives the HELLO packet from A and then join the domain of A. This election process is simple to calculate and suitable for the network perception stage. In addition, domain managers should summarize the received HELLO packets and generates a domain summary message. They exchange messages through gateways to obtain complete network-wide state.

UDP Header	IP Header	Domain Sumary				
		Domain Address	Total Nodes	Relative Speed	Link Changes	Quene Depth

Domain Manager ID (32 bits): the address of manager self
Total Nodes (8 bits): the number of nodes in the domain
Relative Speed (8 bits): the average relative speed of the domain
Link Changes (8 bits): the total number of link changes in the domain
Quene Depth (6bits): the average queue utilization in the domain

(a) HELLO packet format

UDP Header	IP Header	Notice	Parameters				
		Label	Domain Address	Total Neighbors	Relative Speed	Link Changes	Quene Depth

Label (2 bits):added by managers to indicate routing mechanism
Domain Manager ID (32 bits):the address of its manager
Total Neighbors (8 bits): the number of adjacent nodes
Relative Speed (8 bits): the own average relative speed
Link Changes (8 bits): the frequency of Neighbors change
Quene Depth (6bits): the receive buffer queue utilization

(b) Inter-domain packet format

FIGURE 4. **Packet format in first stage.**

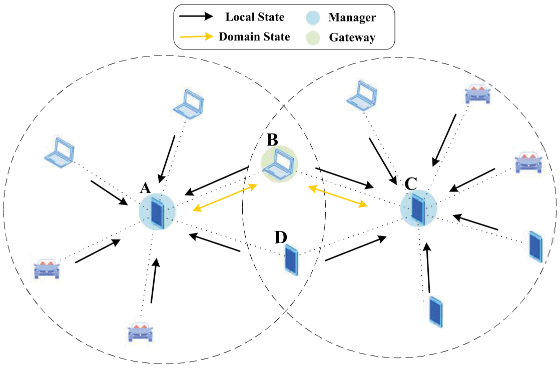


FIGURE 5. **Domain managers and gateways.**

Remain nodes in the domain can be classified into members and gateways. Domain members are responsible for perceiving local information and interacting with the manager. Domain gateways not only need to perform the duties of domain member, but also assist the interaction between managers. Generally, a node that receives HELLO packets from different managers is eligible to become a gateway. However, qualified nodes can register with the domain manager as a new gateway only if there was not effective gateway existed. Specifically, node D in Fig.5 is qualified to be the domain gateway, but node B has already connected two domains so that the registration of D will be refused. The domain managers periodically check links with their gateways, new registration request can be accepted after the previous link failed. In addition, the domain gateway may connect more than two managers.

After dividing the MWN into multiple domains, each domain manager will generate a local network status report based on the member's HELLO message. They collaborate with other managers through multicast to obtain the entire network state, such as average speed and traffic load. It is worth mentioning that the establishment of the domain will

Pseudo code 2: Smart Decision-making

```
Set node i;
if i is domain manager:
   while i need to broadcast HELLO packet:
      input network state into Analysis Model
      ouput routing policy
      record routing policy and generate HELLO packet
   end while
else:
   while i receive HELLO packet from manager
      record necessary information
   end while
end if
```

FIGURE 6. Pseudo code of smart decision.

take some time. During this period, all nodes use the source routing mechanism to send data.

B. SECOND STAGE: SMART DECISION

With the popularity of smart phones, mobile Internet occupies more and more network resources. In order to relieve pressure on access network and backbone network, users can transmit some traffic through a multi-hop network. Nevertheless, different traffic has different requirements for network capabilities. Promising services in multi-hop network can be classified into: Content Delivery, Real-time Transmission, and Emergency Communication. Therefore, nodes must consider the unique demands of the service when establishing and maintaining routes. With this in mind, we have proposed a smart decision scheme and corresponding pseudo code is provided in Fig.6.

In this paper, all domain managers record these parameters: number of nodes, average relative moving speed, average link change rate, and average queue depth. After the first round of collaborative perception, these parameters are initialized. Managers can work out the best routing mechanism and attache result to "Manager notification" field of HELLO message. Obviously, managers need suitable analytical model. The choice of the mechanism is the core issue of in smart decision, and this issue can be regarded as a typical classification problem. Therefore, we adopted a classification model: a nonlinear support vector machine (N-SVM).

SVM was originally a linear binary classifier based on supervised learning. However, it can handle multiple nonlinear classification problems through continuous development. In our N-SVM model, the Gaussian kernel function was used to map the input features to a high-dimensional space, and the sequence minimum optimization algorithm was used to solve the dual problem. The specific kernel function is as follows:

$$K(x, z) = \exp\left(-\frac{\|x - z\|^2}{2\sigma^2}\right) \tag{8}$$

However, in order to achieve effective classification of multiple protocols, we extend the N-SVM based on the one-versus-one ideas. Regularly, only a small-scale data set is required to train of the model. Every node deploys the trained model to the kernel program to enable the smart decision.

After the collaborative perception, each domain manager inputs obtained network parameters into the pre-trained model to predict the optimal routing mechanism. When the manager completes the calculation, the forecast result is appended to the LABEL field at HELLO message. Other nodes follow the instruction from its manager. For instance, nodes will insert topology information to the HELLO message if they are required to adopt the link state-based routing mechanism.

This section introduces the proposed QER protocol, which collects network parameters through collaboration and inputs they into a pre-trained model to find the most appropriate routing method. In the next section, the specific routing mechanisms implemented in QER will be introduced.

IV. IMPLEMENTATION

This section will explain three routing mechanisms actually adoptd in QER, detailed comparison among them are presented. It is worth noting that QER is an scalable solution since other routing methods can be easily integrated.

A. ADOPTED ROUTING MECHANISMS

In order to highlight the superiority and scalability of QER, we have adopted three classic routing mechanisms: source routing, on-demand distance vector routing and link state-based routing. Obviously, the basic ideas of these mechanisms are common in MWN and each of them has unique characteristics. Next, we will introduce them in turn.

Source routing: this is a reactive routing mechanism inspired by DSR which demand nodes to maintain the complete link from the sender to the receiver. It requires nodes to store complete routes to other destinations in local caches. When a node sends a data packet, a route needs to be inserted into the data packet. When the domain manager declares that the node should adopt this mechanism, the routing establishment and maintenance processes of nodes are as follows:

In the event of data packets sending, the sender inquires the local routing table. The routing table contains the Neighbor List so that adjacent terminals can communicate directly to reduce transmission delay. If the route was not found in local cache, the sender will initial the route discovery process to find a valid path. Route discovery means the sender should flooding routing request (RREQ) messages actively. Other nodes will rebroadcast it when they receive the RREQ message, except for the destination node or the node holding the valid route. When the RREQ message is forwarded, the complete route is recorded in RREQ message. Destination generates a route reply (RREP) message when it receive the RREQ. The RREP can Return to the source node because of route embedded in the RREQ. The sender appends the complete path information to the data packet for forwarding and the discovered route will be cached for a long time. On account of source routing records complete path information, no special mechanism is required to detect routing loops.

When a host of packets are lost due to link changes or congestion, related nodes will start the route maintenance process. They will send a routing error (RERR) message to notify the error. On condition that the intermediate node can adopt its cached backup route to the destination, it will change route inserted in the packet and send a RRER to source with the new path. Furthermore, the nodes around the failed link can also initiate the route discovery process directly. If an available path is found, they repair the transmission and notify other upstream nodes. This can enhance reliable delivery of data packets. Similar to DSR, all nodes are capable of promiscuous listening by default to reduce possible routing overhead.

On-demand distance vector routing: this is a reactive routing mechanism like a famous protocol AODV. Nodes discover and maintain routes on demand but this mechanism has a different core idea from source routing.

For route discovery, node will create the traditional routing table to record the next hop of each destination. All nodes are not permitted to keep the full link information to simplifiy the route discovery and route maintenance. Absolutely, neighbor information obtained through collabrative perception is stored in the routing table. When there is no route for a destination, the sender searches for route by flooding the RREQ messages in the same way as source routing. However, once the RREQ transit to a intermediate node, it maintain the reverse routes to the source node. Only once the destination node (or a node that knows the available route to the destination) receives the RREQ message, it unicasts the RREP message through the reverse route to establish effective link. The destination maintains a sequence number to ensure the freshness of routing information and prevent routing loops. In addition, ring search method is exploited to reduce the overhead due to RREQ flooding.

In short, on-demand distance vector routing mechanism only needs to add tuples of destination and next hop to the existing Neighbor List. A node maintain timers for each entries in routing table to judge its availability. An entry will be cleared after a preset time, and then the upstream node will generate a RERR message to inform the previous hop to erase all expired routes. If some nodes still send data to the destination of the erased route, those nodes should initiate the route discovery autonomously.

Link state-based routing: we implement this proactive routing mechanism based on HELLO message extension to achieve route discovery and route maintain. Obviously, the node can collect link information within one hop through HELLO messages. However, the current inter-domain interaction mechanism cannot provide nodes with a complete link state of entire network. Thus when managers decide to enable this mechanism, the link state information will be added to the inter-domain messages. Therefore, domain managers will maintain a complete link state. Once a node needs to find another node, it first checks its Neighbor List to check whether a valid entry is already existed. Otherwise, it requests route from the domain manger, and the manager performs route calculation through the shortest path algorithm based on link state database. After the calculation, manager return the valid path to the requester. The disconnected upstream node should send a RERR to its manager while a link failure occurr. The manager can update its local link state database and multicast it to other managers. After receiving the new database, the new available route will be recalculated.

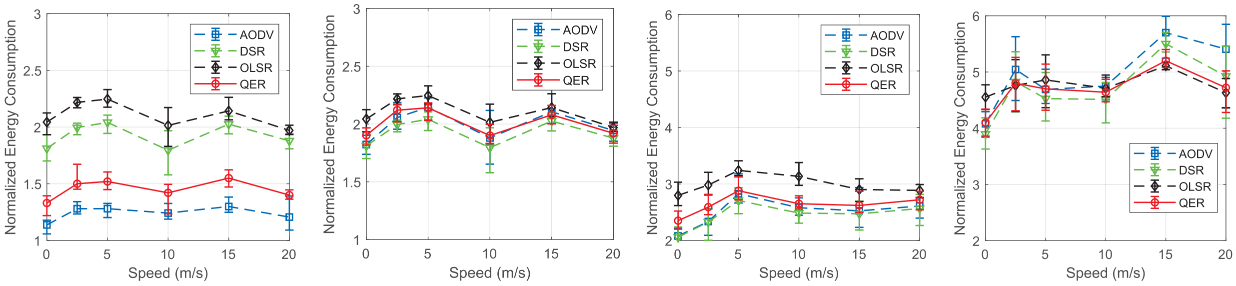
B. FEATURES COMPARISON

There are obvious differences among the above alternative mechanisms, especially their basic ideas are quite various. Past experience shows that a single routing mechanism can only achieve optimal performance in specific scenarios. Therefore, comparing the features of these mechanisms will benefit subsequent performance analysis.

Typically, terminal are not allowed to generate routes in advcance for reactive mechanisms. Only if a terminal intend to transmit data, it initial the route discovery process. Therefore, the routing table within single node is always established on demand, and it is almost impossible to hold the overall topology. Instead, the proactive mechanisms use periodic interaction to maintain a link state table that contains the detailed topology information. It need to detect changes of network topology continuously. Once the source node sends data, it can quickly obtain a valid path. The inherent difference between the two types of mechanisms leads to diverse performance. When reactive mechanisms are enabled, the multi-hop network can adapt to the dynamic scenarios. They can provide good data throughout even if the link state changes rapidly. Nevertheless, the average delay increases as network mobility increases due to tiring route discovery and maintenance. On the contrary, proactive routing often hold low average delay since nodes benefit from link state information. However, this brings too many control signals in the large-scale network.

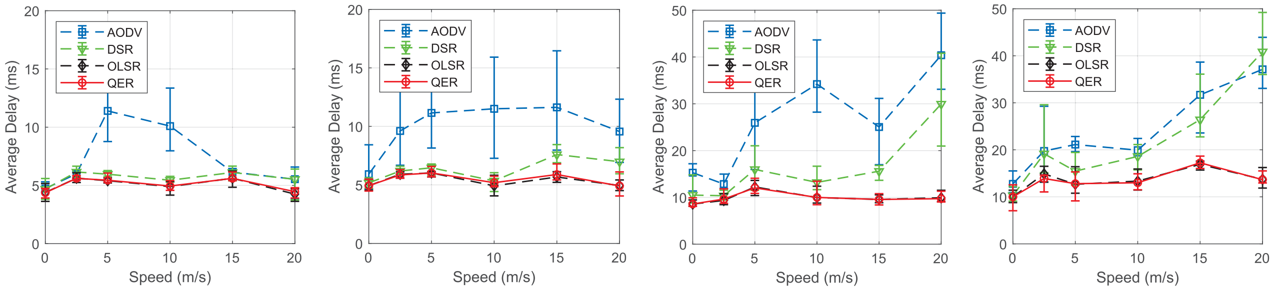
Involved two reactive mechanisms share certain similar characteristics. In particular, they both discover routes only in the presence of data packets in the need for a route to a destination. However, some detailed differences still cause various performance.

First, source routing mechanism can access more routing information than on-demand distance vector routing. For example, the source can learn the route of each intermediate node on the path using a single RREQ-RREP cycle in source routing. Intermediate nodes can also cache the routes of subsequent nodes. In particular, it is possible for a idle node to cache routes because of promiscuous listening. In the absence of complete link information and promiscuous listening, on-demand distance vector routing can only collect limited routing information. This usually result in more network overhead and transmission delay. Second, source routing demand node to learn alternate routes to the destination, which will be useful in the case the primary route fails. Third, there is no mechanism to expire stale routes in the source



(a) Scenario 1 (b) Scenario 2 (c) Scenario 3 (d) Scenario 4

FIGURE 7. Energy consumption comparison.



(a) Scenario 1 (b) Scenario 2 (c) Scenario 3 (d) Scenario 4

FIGURE 8. Transmission delay comparison.

routing. Stale entries are indeed deleted while receiving the RRER, but routing table in other node may be polluted because of promiscuous listening. In contrast, on-demand distance vector routing has a conservative approach. Node can choose the fresher route based on sequence numbers.

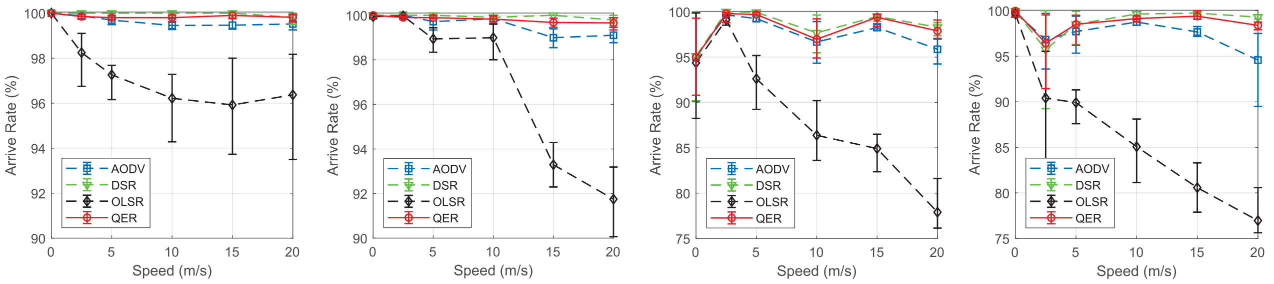
Taken together, inconsistent routing ideas will lead to gaps in transmission performance between different mechanisms. In the next section, we compare the QER protocol with other classic protocols and reveal its superiority.

V. PERFORMANCE ANALYSIS

In this section, we evaluate the three application that we introduced in the previous section. We compared QER with three protocols: AODV, DSR, and OLSR. Simulation was implemented in a common simulation platform NS2 [26] which is a scalable packet-level simulator. The detailed settings were derived from real-world scenes. IEEE 802.11 was used as the MAC protocol with a bandwidth of 2 Mbps at 2.4 GHz radio frequency. And maximum transmission radius of nodes is 250 m. In collaborative perception stage, 2 seconds are set for HELLO packet interval and 5 seconds are set for state perception. Penalty term is set to 1 and gamma coefficient is set to 0.1 for N-SVM in smart decision stage.

Here we present simulations performed by 25 nodes in an area of 500m × 500m and 40 nodes in an area of 1000m × 1000m. There are 25 nodes in scenario 1 and scenario 2, 25% and 50% of them generate data flows respectively. In scenario 3 and scenario 4, 40 nodes are involved and the proportion of traffic is the same as above. Simulation of each scenario will be performed for 20 rounds with different random seeds and a single round was run for a duration of 50 seconds. The mobility in the environment was simulated using a random-waypoint mobility model. In these simulations, velocities ranged from 0 m/s and 20 m/s, while the pause time was set to 0 seconds. In addition, the rate of data flow is set to 1KB/s. We plot the 90% confidence interval as error bars on the figures. We have improved transmission performance from three aspects respectively: energy consumption, transmission delay and packet arrival rate. The test results are as following:

Minimal Energy Consumption: We first set QER to choose the routing mechanism with minimal energy overhead. As shown in Fig.7, nodes need to spend more capacity for data transmission when the number of data flow increases. Results in Fig.7 (a) and (b) shown that the increase of speed has little effect on energy loss in a small area. Under low load conditions, AODV performs best and QER followed. Compared with OLSR, QER has achieved a 32.3% improvement when the average speed is 5 m/s. As the load increases, all four protocols perform similarly. Fig.7 (c) present proves that when traffic load is light, reactive routing is superior to prior routing. In the above three cases, the nodes in QER all adopt reactive routing mechanism. For Fig.7 (d), the energy consumption of reactive routing protocols surpassed proactive routing protocols so that QER switch to link-state mechanism. At the speed of 15m/s, QER saves almost 8.7% of



(a) Scenario 1 (b) Scenario 2 (c) Scenario 3 (d) Scenario 4

FIGURE 9. Average arrive rate comparison.

energy overhead compared to DSR. It can be found that the performance of QER is difficult to attain optimally, this is due to the additional overhead that nodes regularly exchange network status. However, it is foreseeable that QER can always find the routing mechanism which generates the minimum energy consumption in various scenarios. Above all, traffic load is constantly changing in MWN scenarios, QER is able to maintain energy losses at a low level. QER is expected to perform better after integrating energy-oriented routing mechanism.

Minimal Transmission Delay: We next analyze the optimization of transmission delay for QER. Average delay of each protocol are presented in Fig.8. As a consequence of the QER can select the best routing mechanism, it can be clearly found that it often has the lowest latency. In Fig.8 (a) and (b), the performance of OLSR and DSR both great since OLSR is table-driven and DSR maintain routing cache. Due to the simple route maintenance mechanism, AODV performs poorly in latency performance. Through Fig.8 (c) and (d), it is easy to find that as nodes and data flows increase, reactive routing protocols require more resources to find and maintain routes, which has significantly increased transmission delays. Above all, QER keeps latency low through table-driven routing method.

Maximum Arrive Rate: Finally, we switch QER to enhance the packet arrive rate and corresponding results are demonstrated in Fig.9. The packet arrival rate determines the throughput of the network. It can be discovered from all experiments that the table driven protocol OLSR has a poor performance when nodes nodes move fast. Oppositely, on-demand routing protocols perform well in high-speed moving scene. However, the performance of AODV is not satisfactory because of the slower reconstruction of route. For QER, nodes adopt the best-performing source routing mechanism. Available bandwidth is consumed due to regular message exchanges. However, the performance of QER will not be 2% worse than DSR when the network load is high.

Above analysis demonstrates that QER is able to collect the network status and endeavor to meet the service performance requirements through adaptive routing mechanism.

VI. RELATED WORKS

Since there is no infrastructure, the requirements for ad hoc network are quite different from other networks. In order to cope with various application scenarios, some researches have proposed methods to improve the route adaptability.

In order to enhence network flexibility, Lee proposed a new routing scheme called Traffic Aware Dynamic Zone Routing (TA-DZR) which employs the cluster method but forms proactive routing based on the traffic load [27]. However, TA-DZR can only reduce the total energy consumption in a low load scenario. Umar *et al.* [28] proposed state-aware link maintenance approach to perceive whether traffic passing through node, then divide the node into three states. Active nodes will use table-driven routing while inactive nodes will not maintain link state table, which can reduce routing overmanager and improve network efficiency. When nodes move quickly, the performance of this protocol will drop dramatically due to frequent link state changes.

Ladas *et al.* [29] discussed the impact of the node quantity on traditional routing protocols and introduced a hybrid protocol called M-CML. This protocol record the number of nodes in the entire communication area. When the network size is small, the node will adopt an enhanced OLSR protocol. When the number of nodes is large, the node will adopt the AODV protocol. Although this protocol improve routing performance but AODV and OLSR both perform badly in highly mobile scenarios. Tokunaga *et al.* [30] proposed a domaining protocol for high-density areas, which promote network scalability by limiting domain size and multi-layer domaining. But they only evaluated their protocol in low mobility scenarios. Numerous domain managers would make it difficult to use in scenarios where nodes move fast. Yang *et al.* [31] present a protocol integrated directed diffusion and location-based routing to improve transmission rate, shorten transmission range and reduce transmission consumption. Nevertheless, this protocol demands node to enable global position system which consume a lot of energy.

Inspired by the software defined network architecture, Abolhasan et al design a hybrid framework to integrate controllers into wireless access facilities [32]. They proposed to separate routing data and user data into different frequency bands for transmission which can improve the network carrying capacity. It only use the link state exchange protocol, which results in high routing overhead. They have proposed a virtual ad hoc routing protocol [33]. However, this protocol is limited to use in LTE systems and lacks support for heterogeneous networks.

Above works only focus on obtain some key attributes of the network, such as traffic distribution, network size and network density. They get better performance by employing adaptive procedure in specific scenes. However, they are short of comprehensive consideration of different scenarios, this paper just makes up this gap.

VII. CONCLUSION

MWN are seen as important green solutions to the interconnection of terminals. As we discussed in this paper, the real-time state of the network is critical for data transmission. This paper proposed a QER protocol to improve user satisfaction when they use MWN. Firstly, we clarified our definition of MWN and presented formulations for node relative movement speed, link change rate and network load. These parameters have a huge impact on data transmission. Secondly, two stage of QER protocol are introduced in order. Related pseudo-codes of the algorithm are also given to illustrate the specific process. In the perception stage, nodes collaborate to establish a domain, select managers, and exchange status information. In the decision phase, the managers input the collected information into a pre-trained support vector machine model to obtain the optimal routing mechanism and informs the result to other members. Thirdly, we modified three classical routing mechanisms to make them into optional solutions in QER. Experimental results verify the effectiveness of QER, that is, to optimize the QoE for specific targets in various situations. Overall, QER protocol enables nodes to mine network features and make better decisions. In the future, we will continue to improve this protocol and design more secure interaction mechanisms.

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