Implementation and Optimization of AODV for Internet Connectivity

Bingying Cai*, Huimei Lu*, Yong Xiang†, Weitao Wang*, Jingbang Wu*, Rui Gao*
cbying@bit.edu.cn, luhuimei@bit.edu.cn, xyong@mail.tsinghua.edu.cn, wwtao@bit.edu.cn, wjbang@bit.edu.cn, grui@bit.edu.cn
*School of Computer Science, Beijing Institute of Technology, Beijing, China
†Department of Computer Science and Technology, Tsinghua University, Beijing, China

***Abstract*—The popular method for MANET to access the Internet is choosing some gateways through which MANET can act as a subnet of the Internet. In these solutions, gateways will be the bottleneck of the whole network. Meanwhile, gateway selection and handoff are also the problems. Since aforesaid problems, a new protocol was implemented on embedded devices based on iAODV, and route optimization and link failure repair were proposed and implemented for a further step. The interconnected protocol introduced interconnected node (ICN) and wired node (WDN), and was compatible with multiple network interfaces. To access the Internet, the interconnected protocol routed ICN , WDN and WLNwireless node as peers. Experimental results show that in the presence of ICNs and WDNs, the new protocol has higher overall network bandwidth and better data transfer stability than AODV. When the network topology changes frequently, it tries to find a better path by route optimization, and detect or repair the link broken timely by link failure repair. In traditional MANET in which all nodes are wireless, the interconnected protocol has a similar performance to AODV.**

***Index Terms*—MANET, AODV, Connectivity for Internet, Multi-interface routing, Gateway.**

I. Introduction

In countries or areas having network infrastructure at low level or in environment of emergency whose network infrastructure is unavailable, self-organizing, multi-hop and being able to access the backbone are the basic requirements of internal and external communication [1], [2]. Mobile ad hoc network (MANET) can meet the requirements of internal communication, but it has no access to the backbone. There are big differences between MANET and the TCP/IP protocol suite in both setting-up network and routing protocols. Due to these differences, typical practice to access Internet connectivity for MANET is to use the gateway as a communication bridge between the Internet and MANET. In the proposal which adopts gateways, the MANET accesses the Internet through one or more gateways as a subnet. These gateways are responsible for data exchange and protocol conversion between networks. Nodes in MANET are expected to discover and maintain the path to gateways, and then register with the proper one. Thus most researchers focus on the algorithms of gateway discovery and maintenance. Meanwhile, how to select an appropriate gateway discovery approach according to different cost and scenarios is equally important. It's intuitive and well-founded to access the Internet through gateways. However, these gateways are easy to become the bottleneck of integrated Internet and MANET (IIM). Increasing the number of gateways can balance the load of each gateway, but it will bring extra cost of gateway selection and handoff. Moreover, some gateways need to act as foreign agent or home agent (FA/HA) when nodes roam between networks. Problems talked above will make the program of gateway quite complex.

Based on the background above, this paper has implemented and improved the interconnected protocol Internet Ad hoc On-Demand Distance Vector Routing (iAODV) [3]. The iAODV supports wired network interface and integrates the Internet and MANET by routing. It is implemented and emulated in NS2 [4]. In order to access interconnection, AODV was modified to support wired network interface and multi-interface routing. The proposed protocol was named Internet Ad hoc On-Demand Distance Vector Routing with Route Optimization (iAODV-RO). The iAODV-RO routed ICN which has wired interface and wireless interface, WDN which has wired interface, and WLN which has wireless interface as peers, and all nodes shared the same protocol. With the introduction of the wired link, it could lighten the interference caused by sharing radio channel, improve the bandwidth and reduce the packet loss rate. The sub-path consisted of wired links could also be used as a connection between different MANETs.

The remainder of this paper is organized as following: Section II presents related work and discusses about the situation and study of IIM. Section III describes the design of iAODV-RO. Section IV describes the prototype implementation of iAODV-RO in detail. In section V, the experimental environment and scheme are introduced, and the results are analyzed. Finally, conclusion is given in section VI.

II. Related Work

MANET is a no center, self-organizing and multi-hop temporary network which is independent of the network infrastructure. Nodes in MANET are managed by dedicated protocol suite. Thus, when discussing the connectivity between the Internet and MANET, intercommunicating via gateways is a viable alternative. In paper [5], Ali and Hamidian discuss how to implement the interconnection through gateways on NS2. The typical routing protocols of MANET and different approaches of gateway discovery are briefly summarized in this paper. El-Moshrify, Mangoud and Rizk et al. [6] think that all communication between the Internet and MANET must be manipulated by any of the gateways. Furthermore a comparison of reactive gateway discovery, proactive gateway discovery and integrated gateway discovery is given in [6]. However, the cost of gateway handoff is quite expensive when nodes roaming between gateways frequently. In integrated solution, how the node to choose the discovery approach and the range of GWADV is hard to solve. Khan, Ehthesham and Kumar et al. propose a new metric for register gateway selection [7], [8]. The new metric takes the number of hops and the queue length of interface into account to choose register gateway, and to select route between nodes.

The contribution of research mentioned above is how to discover the gateways or what approach of discovery is suitable for special scenario. The common point of them is being implemented and emulated on NS2. Protocol iAODV is implemented on NS2 too, but it tries to settle the bottleneck and handoff issues caused by gateways in the form of routing. IAODV introduces ICNs and WDNs, and modifies AODV to be compatible with multi-interface routing. MANET and wired LAN are regarded as two parts of IIM and can intercommunicates with each other by ICNs. The nodes in IMM runs the same protocol iAODV, so the cost of gateway discovery and maintenance, protocol conversion is cut down.

Ahlund and Zaslavsky put forward an integrated connectivity solution based on the European quickly "City Mobile" project [9], [10], and implement its software prototype [11]. The solution has two aspects: implementation of MIP [12], [13] and AODV on gateways, and modification of AODV to support MIP. This software implementation is a practical effort and the protocol behavior can be observed in the City Mobile called Skelleftea.

After research, we presented an interconnected solution called iAODV-RO based on iAODV and FB-AODV [14]. The iAODV-RO was the implementation and enhancement of iAODV on embedded devices. There was no difference about the interconnected protocol between WLN, WDN and ICN. The iAODV-RO was implemented on embedded devices to verify the feasibility and performance of interconnected protocol. And the influence of real environment on devices could be observed also.

III. Design of Protocol

There are three types of nodes in the interconnected network: WLN, WDN and ICN. ICN is the key to integrate the Internet and MANET. In order to access to the wired LAN, the most important issue is to obtain multiple types of interface and to maintain them. How to modify the AODV to support multi-interface routing is equally important. The structure of iAODV-RO is shown in Fig.1.

Figure 1 illustrates the main modules of iAODV-RO, including network interface initialization and maintenance, neighbor maintenance, link failure process, topology change detection, and routing and optimization module. The parts in dotted boxes are the data structure maintained by the corresponding module.

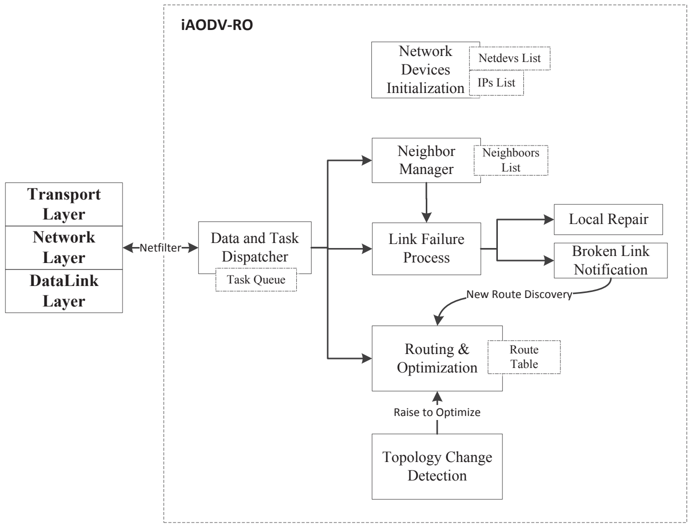

Fig. 1: The structure of iAODV-RO

A. Supporting Multi-interface and Broadcast

To obtain interface list and node type, nodes in IIM read all of the available network interfaces when the system setting up. And then iAODV-RO maintains a list of interfaces and another list of IPs. According to the interface list, node can determine its type and behavior rightly. When the initialization is finished, nodes will broadcast the Hello packets to get local connectivity and their neighbor lists. There are wireless mobile nodes only in plain AODV, thus all packets are sent or received via wireless interface indifferently. In order to make full use of the stability and high bandwidth of wired link, the broadcast process needs to be modified as follows:

a) Packets generated by local process or received from the wireless interface will go out through all wired interfaces (if present) first then wireless interface.

b) Packets received from the wired interface will go out through all wired interfaces except the incoming one, then the wireless interface (if present).

c) The wired interface has a higher priority than the wireless interface when broadcasting.

Since all nodes on the same wired bus can always receive the same broadcast packets, broadcasting to the inlet wired interface is redundant. These adjustments save the bandwidth and avoid flooding the broadcast packets, thereby the network load is reduced to some extent. In addition, wired link is more stable than wireless link and does not have the problems of sharing bandwidth and interfering each other. Therefore, the overall performance of the network is improved because of the introduction of the ICN and WDN.

B. Route Discovery and Link Failure Process

Most protocol process of iAODV-RO follows the definition of RFC3561 [15], but interface information is added to protocol control packets, route entry and neighbor entry. The interface information is used to support multi-interface routing. When node receives RREQ/RREP, it records not only the senders IP but also the inlet interface. Correspondingly, a field named outIface is added to route entry. The next hop of every

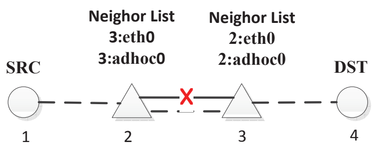

Fig. 2: Local repair of link failure

path is determined by IP address and outIface when a route is established or queried.

Nodes in MANET are mobile, which may lead to a link break or reconnection. In iAODV-RO, the ICN has both wireless and wired interfaces, and they provide a backup link for each other. As shown in Fig.2, SRC uses the path 1-2:eth0-3:eth0-4 to communicate with DST at the beginning. At some point, the wired link is lost for some reason such as interface shutting down or line fault. Node 2 or Node 3 would check the neighbor list automatically, and find that there is a wireless connection which can be used to reach each other. Then link failure process will change the next hop's IP and outIface to the new link in route entry. Finally, the using path became 1-2:adhoc0-3:adhoc0-4. Only when all links are not available, the node sent a RERR to the SRC. Then SRC would try to raise a route discovery process for new path. Local repair, which tries to find a local backup link, is simple and fast. Moreover, it's transparent to other nodes along the path. As a result, the packet loss caused by link failure is low and it doesn't need to start a new discovery process.

C. Route Optimization

WLNs move frequently in MANET, while ICNs and WDNs move rarely. Hence network topology changes due to node mobility and node opening/closing are concentrated in the MANET part. In iAODV and FB-AODV, the transmission path would tend to be stable, which has a long path, after disconnecting many times. Even the ICNs or WDNs available are missed. In IIM, the stability of ICNs and WDNs is higher than WLN's, and the resources are more abundant too. Therefore, the appearance of ICN/WDN neighbor has a great possibility to provide a better path than the using one. In order to exploit the wired link, route optimization triggered by the appearance of ICN/WDN was proposed.

In iAODV-RO, if node along the active path detected a new neighbor of ICN/WDN, it would send a topology change notification packet (TCNP) to the source. When the source received a TCNP, it tries to find a new path by raising a particular route discovery. The source would broadcast RREQs with the R field set to 1 and set a timer to wait for the route optimization. The route established by the optimization RREQ sets its R filed to 1. The main difference between route discovery and route optimization is that the intermediate node having a route to the destination does not generate and return a RREP when it received optimization RREQs. Only when the destination received the optimization RREQ, a RREP with the R field set to 1 is generated and sent to the source. The R field distinguishes the desired route from the transmission route. As a result, the data transmission will not be interrupted and discovery of the new path can work rightly.

When optimization RREQ arrived at destination, the hop count of the new route and the using route would be compared. If the hop count of the using route is less, discard the optimization RREQ and do nothing. Otherwise, destination would generate an optimization RREP and unicast it to source. Source would change the transmission path to the new route and then continue the transmission after received optimization RREP.

IV. Implementation of Protocol

The implementation of iAODV-RO was improved on the basis of FB-AODV and it was loaded into the system as a kernel module. In this paper, iAODV-RO was programed on Android Phone and PandaBoard. PandaBoard is a kind of Android development board with Linaro kernel version. The remainder of this section illustrates the prototype implementation of iAODV-RO on embedded devices from two aspects: the overall architecture and the key protocol processes.

A. Architecture of System

IAODV-RO is implemented on the Android platform, which is encapsulated in a Linux kernel module (.ko). Packets passing through the network layer were hooked by Netfilter and then were routed or forwarded by iAODV-RO. The system was composed of 5 modules, including data/task dispatcher module, initialization module, routing module, and link failure process module. The architecture of iAODV-RO implementation in real system is given as following:

When there is data to send, Netfilter intercepts the data packet of transport layer to network layer, and data/task dispatcher creates a corresponding task and inserts it into the task queue. Protocol control tasks such as scheduled broadcast tasks or route discovery/optimization tasks are maintained by the same queue. The main thread removes one task from the task queue for distribution at a time, then invokes the particular module (such as neighbor maintenance or routing) for processing. When there is data to accept, Netfilter intercepts the data packet of data link layer to network layer, and pushes it into the task queue for being dispatched by the main thread. If the packet is user data packet, it will be handed over to upper layer after being filtered by Netfilter. While if the packet is protocol control packet, all manipulations are performed in the protocol module.

The initialization module is responsible for maintaining network interfaces and managing neighbors, which is the basis of integrating MANET and wired LAN. The routing module is the major part of iAODV-RO, including the route discovery and maintenance, the topology change detection and the route optimization. The link failure occurring during the data transmission is processed by the link failure process module, including the local repair and the RERR notification.

In short, packets passing through the network layer will be routed, forwarded or received directly by the iAODV-RO. Meanwhile route table, neighbor list and other data structure will be established and maintained according to different operation.

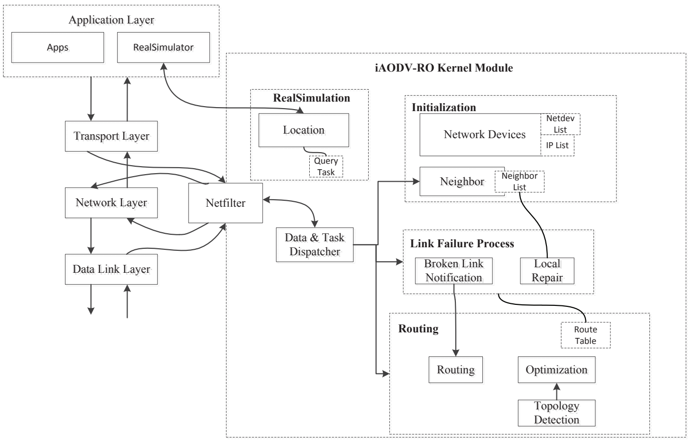

Fig. 3: Architecture of system

B. Route Discovery and Optimization

The major difference between iAODV-RO and AODV in route discovery is that the inlet interface will be recorded in addition to the IP address when receiving RREQs/RREPs. The data flow is directed by the combination of SRC IP, DST IP, NEXT HOP and outIface. Except for normal route discovery, RREQs will be broadcasted into the network when the source receives TCNPs. But these RREQs have R filed set to 1, and the R filed of the response RREPs is 1 too. The particular process is called route optimization process, which is regarded as a special route discovery caused by topology changes.

Nodes receiving RREQs and RREPs judge which process they are in (route discovery or route optimization) according to the R filed. If an intermediate node received an optimization RREQ or optimization RREP and found itself had a route with R filed set to 0, it will create a new route with R field set to 1 after the old one. Thus, data transmission on old route remains the same status. Destination is the only node which generates optimization RREP. When optimization RREQ arrives at destination, the hop count of the using path and the new path are compared. If the using path is shorter, optimization RREP is not sent. Otherwise, send an optimization RREP to the source. If the source received the optimization RREP before timeout, it compares the hop count of the two paths. If the old path has less hops, the source will discard the RREP and expire the new path. If the new path has less hops, the source will remove the old one and set R filed of the new path to 0. With this, the transmission path changes to the found route and data transmission goes on.

C. Link Failure Process

In scenarios of iAODV-RO, there may be more than one connection between multiple interface nodes. So local repair was introduced into the protocol. Nodes would try it first when a link failure appears. When a node along an active path detects a disruption of its next hop, the node checks the neighbor list to know if there are any other connections with the lost neighbor. If there is a connection to the same node, the next hop is replaced with it. The adjacent nodes at both ends of the lost link will try local repair. So both the forward path and the reverse path are repaired. The other parts of this path are the same as before. As a result, the data packets pass through the same next node with a different interface. If no other connection exists, RERR is generated and sent by current node to inform the source. The current node would try every available connection before sending a RERR.

TABLE I: AVERAGE BANDWIDTH

Device-Device	Link Type	Avg Bandwidth	Shorthand
PandaBoard-PandaBoard	Wired	12023(KB/s)	WD-Pbs
PandaBoard-PandaBoard	Wireless	1114(KB/s)	WL-Pbs
PandaBoard-Phone	Wireless	507(KB/s)	WL-PbPh
Phone-Phone	Wireless	539(KB/s)	WL-Phs

V. Analysis of Experiments

A. Experimental schemes

Experimental equipment contains Android phones and PandaBoards. Both kinds of devices are Android devices, but their Linux kernel versions are different. The Android phones serve as the mobile WLNs in the IIM, and can only use the WiFi for communication. While PandaBoards equip with both wired interface and wireless interface, so they can serve as all kinds of node. In order to validate the correctness and performance of iAODV-RO, several sets of experiments as following are to perform: basic performance tests, link failure experiments, route optimization experiments, and collision domain experiments. Details of the experimental topology and experimental method are described below.

1. Topology and description of link failure experiment

There is 30-MB data to send in this experiment. As shown in Fig.4, the path from SRC to DST is “wireless link-wireless link-wired link” at the beginning. After 45s, connection 1 is lost. Then another 45s later, connection 2 is broken too. Finally, both of wired link and wireless link are up again at 110s, and stay stable until the data transmission is completed.

2. Topology and description of route optimization experiment

There is 25-MB data to send in this experiment. As shown in Fig.5, the path from SRC to DST is “wireless link-wireless link-wired link” at the beginning, and node 5 is outside the communication range of other nodes. Besides, node 5 is an ICN node. About 25s later, node 5 shows up and it is a new neighbor of all nodes. The data transmission continues until all data is sent.

3. Topology and description of collision domain experiments

The topology of collision domain experiments is shown in Fig.6. The data transmission will last for 180s, and the length of path in every experiment is 3 hops. There are 3 tests as following:

a) Case 1. One collision domain and wireless link only: All nodes are WLNs and they share the same collision domain.

b) Case 2. Not isolate the collision domain: Nodes 1 and node 4 share the same collision domain, but cannot communicate with each other directly. There is interference among WLNs.

c) Case 3. Separate the collision domain: Node 1 and node 4 are outside the communication range of each other, meaning that no wireless interference exists.

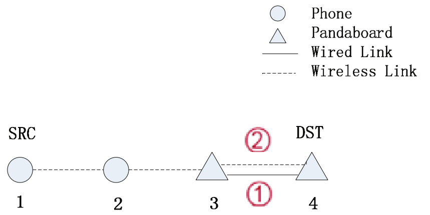

Fig. 4: Topology of link failure experiment

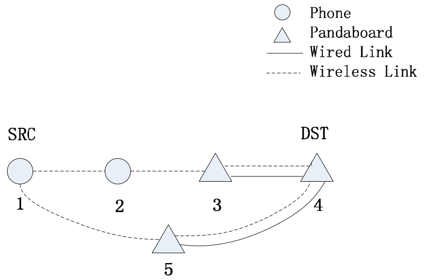

Fig. 5: Topology route optimization experiment

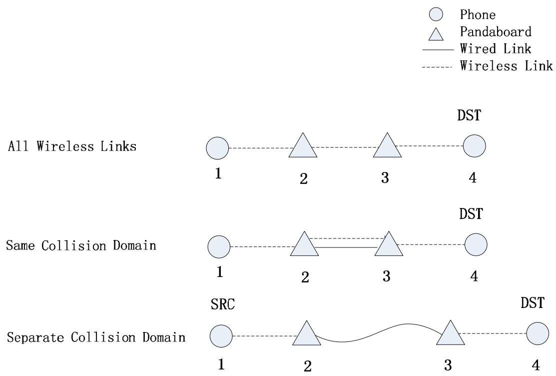

Fig. 6: Topology of collision domain experiments

The table above lists the average bandwidth of different devices combinations in one hop. These bandwidth values are the upper limit bandwidth of multi-hop. For convenience, the shorthand of the bandwidth of different combination is given out in the table. As shown in the table, the bandwidth of the wired link is much better than that of the wireless. Furthermore, it is well known that wired link is stable and do not interfere the data flow on other links. Thus, using wired link with high priority helps improve the performance of iAODV-RO.

B. Link Failure Experiment

Figure 7 shows that the bandwidth ranges from 200-KB/s to 260-KB/s during the first 45s after the data starts to transmit. Then it is reduced to the range of 80-KB/s and 200-KB/s after the wired link is lost. Another 45s later, the bandwidth is reduced to zero because the wireless link is unavailable as the wired link. Finally, the bandwidth goes up to the level of the first 45s. Figure 8 shows the data flow rate between nodes. As can be seen in Fig.8, the variation of the data flow along the path is consistent with the overall bandwidth's. There are four stages in this case. In the first 45s, the path consists of

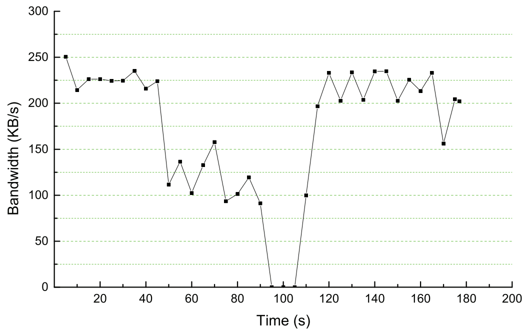

Fig. 7: Curve of the bandwidth of iAODV-RO in link failure experiment

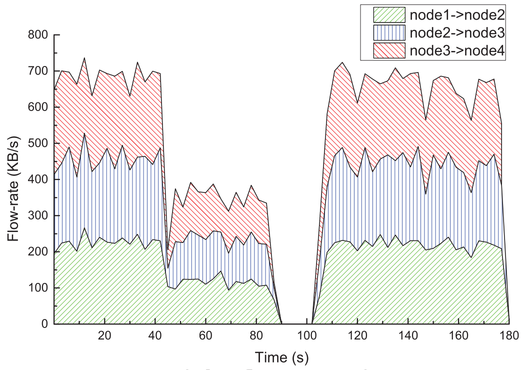

Fig. 8: Constitution of the flow rate of iAODV-RO in link failure experiment

two wireless links and one wired link, thus the flow rate of each node is roughly half of WL-Phs. During the period of 45s to 90s, the wired link is down while the wireless link between node 3 and node 4 is available. All links along the path are wireless, so the flow rate is reduced to 1/3 of WL-Phs. In the third stage, no connection exists between node 3 and node 4. As a result, the destination becomes unreachable. This stage will last for 20s and both links are restored. The data flow rate of the last stage indicates that the wired link is used again when the new path setting up.

The experimental result shows that different links can serve as the backup link for others, which providing a mechanism to switch link quickly. The curves in both figures show that the path with wired links outperforms the path with wireless links only in terms of bandwidth and stability. Besides, the wired connection is involved in the route discovery process and in the link disruption recovery. It indicates that wired link is the preferred alternative for routing.

C. Route Optimization Experiment

As shown in Fig.9, the bandwidth mainly ranges from 200-KB/s to 300-KB/s before 35s. At the point of 35s, node 5, which is ICN, appears and the bandwidth rises sharply to above 930-KB/s. While the AODV does not response to this change and the bandwidth remains the same. To complete the data transmission, the iAODV-RO takes 54s while the AODV takes 102s. Figure 10 shows the constitution of flow rate of iAODV-RO. As can be seen in Fig.10, the data flow is smooth

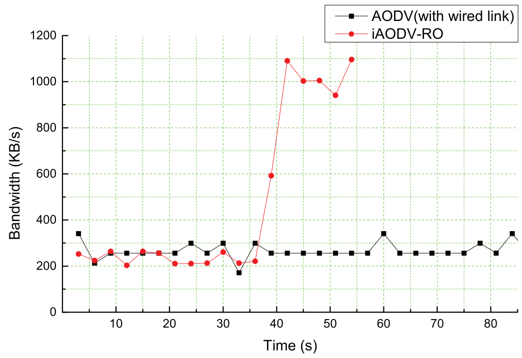

Fig. 9: Curves of the bandwidth of AODV and iAODV-RO in route optimization experiment

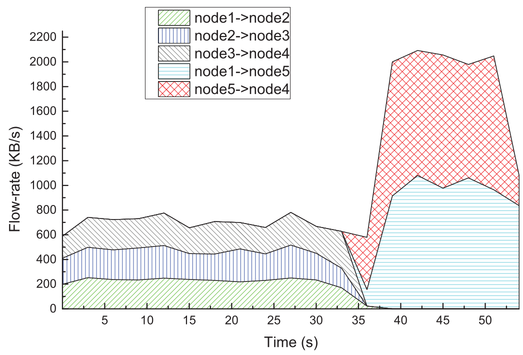

Fig. 10: Constitution of the flow rate of iAODV-RO in route optimization experiment

before 35s. Then the transmission path changes to 1-5-4. Node 2 and node 3 complete the current traffic of them, then no data will pass through. The rest of the data will be transferred along the new path with high flow rate.

The experimental result shows that the route optimization is launched when ICNs show up around active nodes. And the transmission path will switch to the better route if it exists. Notably, jitter may occur during the period of detecting ICN neighbor to completing path switch. Although the route optimization brings the cost of route discovery and the delay of route handoff, the overall bandwidth is improved and the time to finish is shortened.

D. Collision Domain Experiments

The collision domain experiments are set to validate the performance of iAODV-RO when the WLNs are far enough to separate the collision domain by the wired links. As shown in Fig.11, the bandwidth from high to low are as follows: separate collision domain, same collision domain, all links are wireless, and the smoothness of bandwidth curves are in descending order.

When there are only WLNs in the path, the average bandwidth is about 167-KB/s, which is lowest. Besides, the data transmission is most unstable with serve mutual interference and high packet loss rate. When there is a wired connection between two wireless connections, but all nodes are in the same collision domain, the bandwidth is about 279-KB/s. As can be seen from the curve, the data transmission is unstable

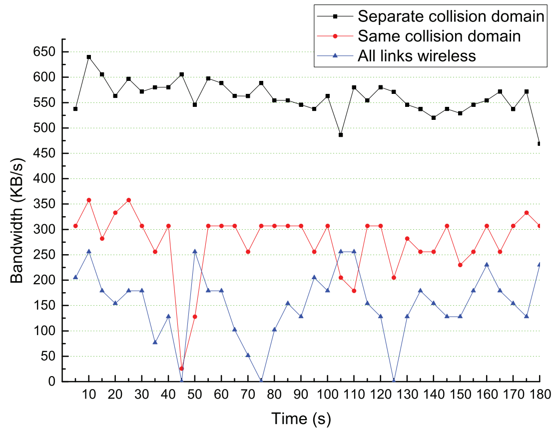

Fig. 11: Curves of the bandwidth of AODV and iAODV-RO in route optimization experiment

and jitter appears occasionally. The bandwidth and packet loss rate in this case is in the middle of the three cases. When the wired link is long enough to separate the WLNs into different collision domain, the average bandwidth is about 560-KB/s which is highest. Besides, the data transmission is more stable than other cases with slight jitter and low packet loss rate.

The average bandwidth ratios of case 1 to WL-Phs, case 2 to WL-Phs, and case 3 to WL-Phs are 1/3, 1/2, and 1 respectively. These ratios mean that the hops existing interference in each case are 3, 2 and 1 respectively. Due to the characteristics of multi-hop wireless transmission [16], [17], the interference will worsen with the increase in node, leading to a sharp decline in bandwidth and a sharp increase in packet loss. Therefore, the presence of wired links in the path can improve the transmission rate and lighten the interference between nodes.

VI. Conclusion

The iAODV-RO was the extension of iAODV to support the interconnection on embedded devices. And route optimization and local repair were proposed to adapt to the frequent changes of network topology. It was a feasible method to set up temporary network and access external network services without infrastructure. The multi-interface routing enabled the nodes to participate in the IIM with different roles, and to use the appropriate link to construct the route. The presence of wired sub-path in the transmission path reduced the conflict between wireless links, and improved the bandwidth and stability of data flow. Especially when the wired sub-path was long enough to isolate the collision domain of WLNs, these advantages were more prominent. In addition to supporting multi-interface routing, the route optimization was proposed. The route optimization was initiated by new ICN neighbors or WDN neighbors instead of all new neighbors. There were two considerations for this design: One was to balance the overhead of route optimization because optimization for all kinds of nodes would be launched too frequently. The other one was to enable source to detect whether there were better paths than the using path when the topology changed. In iAODV and FB-AODV, the transmission path might become long with the nodes moving rarely when the network environment changed frequently. Even if a shorter path showed up, the source didn't sense it and still used the old path which was no longer the optimal path. However, iAODV-RO could solve this dilemma with route optimization.

At present, the multi-interface routing, the interconnection with wired LAN and route optimization were implemented. Next, we consider to design a new routing metric to select the route. The major direction is how to determine the influence of the wired link on transmission path, and then determine how to calculate the metric value. In addition, we consider to introduce NAT to map the flat IP address space in MANET to the existing hierarchical network structure.

References

[1] C. Kobel, W. Baluja Garcia, and J. Habermann, "A survey on wireless mesh network applications in rural areas and emerging countries," in *Global Humanitarian Technology Conference (GHTC), 2013 IEEE*. IEEE, 2013, pp. 389–394.

[2] Y.-N. Lien, H.-C. Jang, and T.-C. Tsai, "A manet based emergency communication and information system for catastrophic natural disasters," in *Distributed Computing Systems Workshops, 2009. ICDCS Workshops' 09. 29th IEEE International Conference on*. IEEE, 2009, pp. 412–417.

[3] W.-Z. Sun, Q.-Z. Zhang, and Y. Xiang, "Extension of aodv for integrated internet-manet," *Computer Engineering and Design*, vol. 34, no. 5, pp. 1521–1526, 2013.

[4] T. Issariyakul and E. Hossain, *Introduction to network simulator NS2*. Springer Science & Business Media, 2011.

[5] A. Hamidian, "A study of internet connectivity for mobile ad hoc networks in ns 2," *Department of Communication Systems, Lund Institute of Technology, Lund University*, 2003.

[6] H. El-Moshrify, M. Mangoud, and M. Rizk, "Gateway discovery in ad hoc on-demand distance vector (aodv) routing for internet connectivity," in *Radio Science Conference, 2007. NRSC 2007. National*. IEEE, 2007, pp. 1–8.

[7] K. U. R. Khan, M. Ehthesham, M. Kumar, and R. U. Zaman, "An effective gateway discovery mechanism in an integrated internet-manet (iim)," in *Ultra Modern Telecommunications & Workshops, 2009. ICUMT'09. International Conference on*. IEEE, 2009, pp. 1–7.

[8] R. Kumar, M. Misra, and A. K. Sarje, "An efficient gateway discovery in ad hoc networks for internet connectivity," in *Conference on Computational Intelligence and Multimedia Applications, 2007. International Conference on*, vol. 4. IEEE, 2007, pp. 275–282.

[9] C. Ahlund and A. Zaslavsky, "Mobile city," *Ad Hoc Wireless Network Support for Regional Communities. The Path to 4G Mobility (September 2001)*, 2001.

[10] C. Ahlund, A. Zaslavsky, and M. Matskin, "Supporting mobile business applications in hot spot areas with pervasive infrastructure," in *The First International Conference on Mobile Business (G Doukidis 08 July 2002 to 09 July 2002)*. Mobicom European Project, 2002, pp. 1–6.

[11] C. Åhlund and A. Zaslavsky, "Software solutions to internet connectivity in mobile ad hoc networks," in *Product Focused Software Process Improvement*. Springer, 2002, pp. 559–571.

[12] U. Jönsson, F. Alriksson, T. Larsson, P. Johansson, and G. Q. Maguire Jr, "Mipmanet: mobile ip for mobile ad hoc networks," in *Proceedings of the 1st ACM international symposium on Mobile ad hoc networking & computing*. IEEE Press, 2000, pp. 75–85.

[13] C. E. Perkins and I. Mobile, "Design principles and practices," *Wireless Communications Series, Addison-Wesley*, 1998.

[14] M. Catalan-Cid, J. L. Ferrer, C. Gomez, and J. Paradells, "Contention- and interference-aware flow-based routing in wireless mesh networks: design and evaluation of a novel routing metric," *EURASIP Journal on Wireless Communications and Networking*, vol. 2010, p. 106, 2010.

[15] C. Perkins, E. Belding-Royer, and S. Das, "Ad hoc on-demand distance vector (aodv) routing," Tech. Rep., 2003.

[16] K. Jain, J. Padhye, V. N. Padmanabhan, and L. Qiu, "Impact of interference on multi-hop wireless network performance," *Wireless networks*, vol. 11, no. 4, pp. 471–487, 2005.

[17] M. Kodialam and T. Nandagopal, "Characterizing achievable rates in multi-hop wireless networks: the joint routing and scheduling problem," in *Proceedings of the 9th annual international conference on Mobile computing and networking*. ACM, 2003, pp. 42–54.

Bingying Cai received B.S in Beijing Institute of Technology in 2013. She is currently working toward a M.S degree in Beijing Institute of technology. Her research interest is ad hoc networks.

Huimei Lu is an associate professor of Beijing Institute of Technology. She received Ph.D. from Tsinghua University. Her research interest includes delay tolerant networks, multicast routing.

Yong Xiang is an associate professor of Tsinghua University. He received Ph.D. from Tsinghua University, M.S. and B.S. from Beijing Normal University. His research interest includes CSCW, ad hoc networks and operating system.

Weitao Wang received B.S in Hebei University of Technology in 2013. He is currently working toward a M.S degree in Beijing Institute of technology. His research interest is delay tolerant networks.

Jingbang Wu received M.S. in Beijing Institute of Technology in 2014, B.S in Xiangtan University in 2011. He is currently working toward a Ph.D degree in Beijing Institute of technology. His research interest is ad hoc networks.

Rui Gao received B.S. in Liaoning University in 2015. She is currently working toward a M.S. degree in Beijing Institute of technology.