

Detection Time Reduction of Multiple Transmission Routes Satisfying Required Throughput in Wireless Multihop Networks

Yuki KUBO, Hiroaki HIGAKI

Abstract—In wireless multihop networks, transmission capacity of each wireless node is relatively low and wireless signal transmissions of neighbor wireless nodes might interfere each other. Thus, it is difficult for a wireless multihop transmission route to provide required throughput to a network application. The authors have proposed a method to provide required throughput by combination of multiple wireless multihop transmission routes with joins and branches based on Ford-Fulkerson algorithm for maximum flow calculation in wired networks. Here, by using capacities of wireless nodes and flows along wireless links in wireless multihop networks, flow increasing wireless multihop routes are searched and detected until the required throughput can be provided. However, there are no cut-off conditions of search for flow increasing wireless multihop transmission routes, longer calculation time cannot be avoided. This paper proposes the cut-off conditions based on the current assignment of flow in wireless links within a wireless transmission range of each wireless node. The reduction of route search time duration is evaluated in simulation experiments.

Keywords—Wireless Multihop Networks, Throughput Requirement, Multiple Route Detection, Maximum Flow Problem.

I. Introduction

In wireless multihop networks such as wireless sensor networks, wireless mesh networks and wireless ad-hoc networks, data messages are transmitted along a wireless multihop transmission route from a source wireless node to a destination one. For support wireless multimedia applications which requires realtime data message transmissions in wireless multihop networks, capacity of wireless communication links along a wireless multihop transmission route is required to be reserved before the source wireless node starts to transmit a sequence of data messages. We have proposed a capacity reservation method which detects a set of wireless multihop transmission routes with joins and branches satisfying the capacity required by a network application. Here, the conventional Ford-Fulkerson algorithm for achieving the maximum available capacity in a wired network is extended to support the broadcast-based wireless networks. Capacity reservation in the internet is distributed realized by RSVP (resource reservation protocol). This paper assumes a centralized managed networks such as those supported by OpenFlow [1]. A centralized controller such as the OpenFlow Controller manages the unreserved capacity in each wireless node and calculates the reserved

capacity in each wireless communication links. As a result, reservation request control messages are transmitted from the OpenFlow Controller to OpenFlow Switches, which are intermediate wireless nodes and their 1-hop neighbor wireless nodes in wireless multihop networks.

II. Related Works

A wired network consists of a set $N' := \{N_i\}$ of wireless nodes N_i and a set $L' = \{|N_i N_j|\}$ of wired communication links $|N_i, N_j|$. Each wired link has its initial capacity and its current capacity $c(|N_i N_j|)$ whose difference has already been reserved by some data message multihop transmissions. Ford-Fulkerson algorithm [3] is one of the well know maximum flow calculation algorithm which determines reserved capacity $r(|N_i N_j|)$ in each wired communication link $|N_i, N_j|$ giving the maximum capacity of a wired multihop transmission route. Here, a sequence of wired multihop transmission routes from a source node N^s to a destination one N^d are detected one-by-one, each of which increases the reserved capacity from N^s to N^d . For a wired multihop transmission route $R = \{|N_0 \dots N_n|\}$, if $c(|N_i N_{i+1}|) = 0$ is satisfied for all wired communication links $|N_i N_{i+1}|$, R is trivially a capacity increasing multihop transmission route. In Ford-Fulkerson algorithm, even if the current capacity of a wired communication link $|N_i N_{i+1}|$ is zero, i.e., $c(|N_i N_{i+1}|) > 0$, a wired multihop transmission route containing an opposite directional wired communication link $|N_i N_{i+1}|$ can be a capacity increasing wired multihop transmission route if $r(|N_i N_{i+1}|) > 0$. Hence, the conditions of a capacity increasing wired multihop transmission route are as follows:

- (1) For all wired communication links $|N_i N_{i+1}| \in R$, $c(|N_i N_{i+1}|) > 0$.
- (2) For all wired communication links $|N_i N_{i+1}| \in R$, $c(|N_i N_{i+1}|) > 0$ or $r(|N_i N_{i+1}|) > 0$.

By application of the rule (2), detected capacity increasing wired multihop transmission routes can have joins and branches; i.e., the configured set of wired multihop transmission routes looks like a mesh.

III. Proposal

A. Extension of Ford-Fulkerson in Wireless Multihop Network

Same as in wired networks, capacity reservation for realtime multimedia data message transmissions is also

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required in wireless multihop networks where initial capacity is much more restricted than in wired networks. Hence, it seems possible for the Ford-Fulkerson algorithm to be naively applied to wireless multihop networks. However, it is impossible directly to be applied since wireless data message transmission model is different from that in wired networks. As shown in Figure 1, when a wireless node transmits a data message to one of its neighbor wireless node, the data message reaches to all the 1-hop neighbor wireless node of the sender wireless node because of the broadcast based data message transmissions in wireless networks. Hence, the capacity of a sender wireless node N can be shared among multiple wireless communication links initiated from N . Thus, a capacity management model where initial and current available capacity is assigned to wireless nodes and reserved capacity is assigned to each wireless communication link. In addition, for data message transmission from a sender wireless node N_s to a receiver wireless node N_r which are 1-hop neighbor wireless nodes one another, not only capacity of N_s and N_r but also capacity of their 1-hop neighbor wireless nodes are consumed; i.e., assigned for reservation.

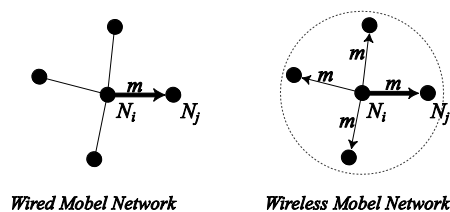


Figure 1. Capacity Assignment Model.

Due to this capacity management model for wireless multihop networks, a wireless node N cannot be an intermediate wireless node of a capacity increasing wireless multihop transmission route if its capacity or the capacity of its 1-hop neighbor wireless node is zero. Otherwise, a trivial capacity increasing wireless multihop transmission route is one whose intermediate wireless nodes and all their 1-hop neighbor wireless nodes have available capacity, i.e., their current capacity is not zero.

B. Capacity Increasing Wireless Multihop Transmission Routes and Cut-off of Route Search

The proposed extension of Ford-Fulkerson algorithm for wireless multihop networks also detects a set of capacity increasing wireless multihop transmission routes from a source wireless node to a destination one one by one. For each detected capacity increasing wireless multihop transmission route, the same capacity is additionally reserved for each wireless communication links between the two successive intermediate wireless nodes along the detected capacity increasing wireless multihop transmission route. As discussed in the previous section, for each wireless 1-hop transmission between the two successive intermediate wireless nodes, the intermediate wireless nodes themselves and all their 1-hop neighbor wireless nodes reduce their capacity. Thus, intuitively, capacity of no intermediate wireless nodes and no 1-hop neighbor wireless nodes is zero.

However, same as the original Ford-Fulkerson algorithm, zero capacity intermediate wireless nodes and/or zero capacity 1-hop neighbor wireless nodes can be exists in an additional capacity increasing wireless multihop transmission routes. For example, if an additional capacity increasing wireless multihop transmission route contains a wireless communication link $|NN'$ where $c(|NN'|) = 0$ and $r(|N_iN_{i+1}|) > 0$, the capacity of N , N' and their 1-hop neighbor wireless nodes might be increased. That is, this capacity increasing wireless multihop transmission route is acceptable. In [5], in order to achieve as much end-to-end capacity as possible, all the possible capacity increasing wireless multihop transmission routes are required to be detected. Hence, all the possible wireless multihop transmission routes are detected one by one and then evaluated if it is acceptable as a capacity increasing route. Therefore, longer time duration is required to terminate the algorithm.

For capacity reservation required by a network application, short time duration search is also required. Hence, certain cut-off method of route search is required to be introduced. As shown in Figures 2–9 the update of available capacity in each wireless node is updated in accordance with an additional wireless multihop transmission route is as follows:

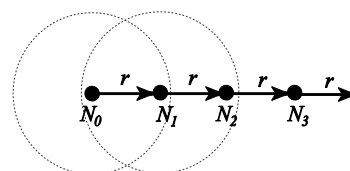


Figure 2. Capacity Update due to Additional Wireless Transmission Route (1).

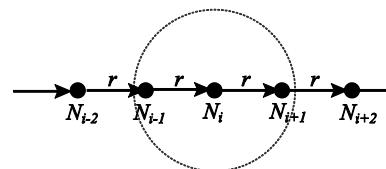


Figure 3. Capacity Update due to Additional Wireless Transmission Route (2).

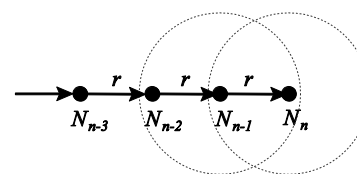


Figure 4. Capacity Update due to Additional Wireless Transmission Route (3).

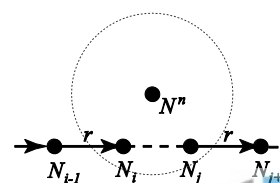


Figure 5. Capacity Update due to Additional Wireless Transmission Route (4).

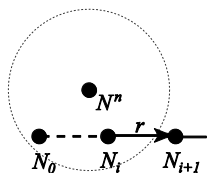


Figure 6. Capacity Update due to Additional Wireless Transmission Route (5).

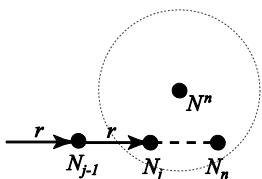


Figure 7. Capacity Update due to Additional Wireless Transmission Route (6).

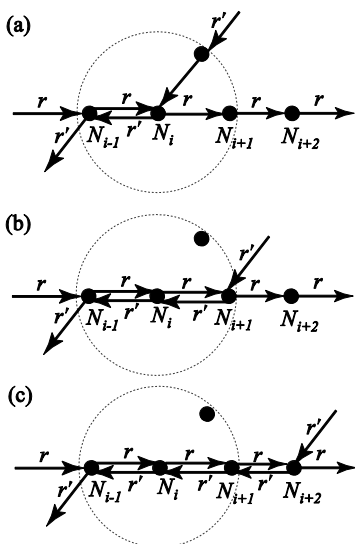


Figure 8. Capacity Update due to Additional Wireless Transmission Route (7).

[Capacity Update in Wireless Node]

Suppose that l^- and l^+ are the numbers of wireless links included in or crossing the edge of wireless transmission range of a wireless node N with usual direction, i.e., its direction is the same as the capacity available one, or reverse direction, i.e., its direction is different from the direction for which capacity has already reserved, respectively, for a newly detected wireless multihop transmission route from a source wireless node to a destination one. Here, the capacity of N is updated as follows; $c(N) = c(N) - l^+r + l^-r$ where r is reserved capacity for the wireless multihop transmission route. □

Hence, if $l^- < l^+$ is satisfied, that is, the number of reverse directional wireless communication links is less than the number of usual directional wireless communication links included in or crossing the edge of wireless signal

transmission range of N , $c(N)$ decreases by the capacity reservation. That is, for the capacity reservation, $c(N) > 0$ should be satisfied. On the other hand, if $l^- > l^+$ is satisfied, that is, the number of reverse directional wireless communication links is more than the number of usual directional wireless communication links included in or crossing the edge of wireless signal transmission range of N , $c(N)$ increases by the capacity reservation. That is, for the capacity reservation, even $c(N) = 0$ is acceptable. Therefore, the following cut-off method is induced for reduction of time duration for route search with less loss of reserved end-to-end capacity:

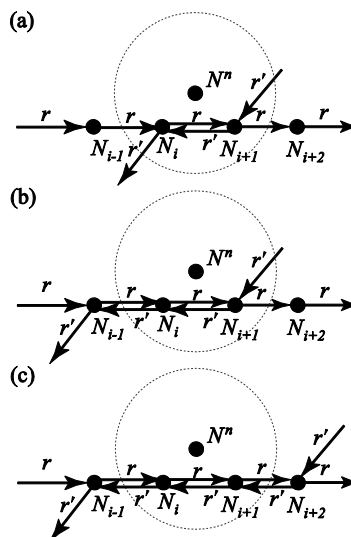


Figure 9. Capacity Update due to Additional Wireless Transmission Route (8).

[Route Search Cut-off Method]

Consider a route prefix $\|N_0 \dots N_i\|$ from a source wireless node N_0 to a certain wireless node N_i different from a destination wireless node N_n . $\|N_0 \dots N_i\|$ never be a prefix of a capacity increasing wireless multihop transmission route from N_0 to N_n if $l^- < l^+$ is satisfied for a certain wireless node which is included in the prefix or a 1-hop neighbor wireless node of the node in the prefix. In search for capacity increasing wireless multihop transmission route, if the above condition is satisfied at N_i , the search is given up at N_i , i.e., a cut-off of the route search is applied at N_i . □

IV. Evaluation

In order to evaluate the proposed method in the previous section, we show the results of the simulation experiments in this section. A simulation field is a $700\text{m} \times 700\text{m}$ square and 100–130 wireless nodes with a 100m transmission range are randomly distributed due to the unique distribution randomness. A source and a destination wireless nodes are fixed as shown in Figure 4, and an initial capacity of each wireless node is determined to be the distance from the center of the simulation field plus 0.1–0.3 randomly determined margin [Mbps]. Based on the depth first search, capacity increasing wireless multihop transmission routes

are detected one by one. The totally reserved capacity and the time duration required for the capacity increasing wireless multihop transmission routes are evaluated. The following three methods are compared:

- (1) Extension of Ford-Fulkerson with the proposed cut-off (Proposal)
- (2) Extension of Ford-Fulkerson without the proposed cut-off
- (3) No reverse directional wireless communication links, i.e., wireless multihop transmission routes without joins and branches

TABLE I. RESERVED CAPACITY IN SIMULATION EXPERIMENTS.

Number of Nodes	Reserved Capacity		
	(1)	(2)	(3)
100	0.3261	0.3261	0.3249
110	0.3888	0.3893	0.3848
120	0.4367	0.4372	0.4337
130	0.4756	0.4757	0.4719

Table 1 shows the reserved capacity by the above three methods. In accordance with the original Ford-Fulkerson method, our proposed extended method for wireless multihop networks in [5] achieves 0.3–1.0% more capacity than the no reverse directional wireless communication method. In addition, the proposed cut-off method does not affect the achieved capacity, i.e., only reduction of 0.0–0.14% of reserved capacity.

TABLE II. REQUIRED TIME DURATION IN SIMULATION EXPERIMENTS.

Number of Nodes	Required Time Duration		
	(1)	(2)	(3)
100	0.29	1.02	1.27
110	2.46	56.80	90.77
120	27.62	127.04	153.26
130	177.31	762.19	961.31

Table 2 shows the required time duration for detection of multiple capacity increasing wireless multihop transmission routes in simulation experiments. The proposed method requires only 4.3–23.3% time duration in comparison with the other two methods. Hence, the cut-off does not reduce the reserved capacity so much and the required time duration is considerably reduced.

v. Conclusion

This paper proposes an extension of Ford-Fulkerson algorithm for reservation of capacity of a set of wireless multihop transmission routes with joins and branches. Here, the purpose is not for achieving the maximum capacity but

for reservation of the required capacity, the cut-off method for search is introduced and is expected to reduce the required time duration. As expected, very little reservation capacity is lost but considerably required time duration is reduced

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