Channel Assignment Protocol with Weaker Restrictions in Wireless Multihop Networks

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ABSTRACT

In wireless multihop networks such as wireless ad-hoc networks, sensor networks and mesh networks, contentions and collisions reduce throughput of data message transmissions. For achieving contention- and collision-free networks, algorithms for assignment of one of multiple communication channels to each wireless communication link has been proposed. However, the ratio of successful channel assignment in the conventional algorithms is not so high due to too hard restrictions on channel assignment. This paper proposes a channel assignment algorithm with weaker restrictions where possible collisions at nodes out of wireless multihop transmission routes are allowed. Based on the novel algorithm, a backward-type channel assignment protocol is designed. Simulation results show that our protocol achieves higher assignment ratio than the conventional protocols with more than 6 communication channels in each wireless communication link.

1 Introduction

A wireless network consists of stationary and/or mobile nodes with wireless communication devices. For achieving higher reachability with less battery consumption and less contentions and collisions, wireless multihop networks such as wireless ad-hoc networks, sensor networks and mesh networks have been proposed. Each wireless node serves not only a role of a source and a destination node but also an intermediate node which forwards data messages from its previous-hop node to its next-hop node along a wireless multihop transmission route. Different from wired communication through cables, wireless communication is based on broadcasting and collisions of data messages are required to be avoided or reduced for achieving higher throughput. As in widely available wireless LAN protocols, e.g., IEEE802.11 and Bluetooth, multiple communication channels are available for wireless nodes and data messages transmitted by using different communication channels do not collide even though their transmission areas are overlapped. Thus, it is expected for wireless multihop transmissions of data messages to achieve higher throughput by channel assignment to each wireless communication link along wireless multihop transmission routes by realizing contention- and collision-free data message transmissions. However, the number of communication channels for a wireless communication link is not so large that channel assignment algorithms for higher successful assignment ratio is required. This paper proposes a novel algorithm with weaker restrictions on channel assignment and designs a channel assignment protocol in which communication channels are assigned in a backward direction along a wireless multihop transmission route for shorter time overhead and higher data message throughput.

2 Related Works

A wireless multihop network $\langle \mathcal{N}, \mathcal{L} \rangle$ consists of wireless nodes $N_i \in \mathcal{N}$ with wireless communication devices and wireless communication links $|N_p N_q\rangle \in \mathcal{L}$ where N_q is included in a wireless transmission range of N_p and data messages are transmitted through it from N_p to N_q. This paper assumes that all wireless communication links are symmetric or bi-directional, i.e., $|N_q N_p\rangle \in \mathcal{L}$ iff $|N_p N_q\rangle \in \mathcal{L}$. Each wireless communication links are multiplicated by multiple communication channels with different wavelengths. Communication links with different communication channels are independent, i.e. contention- and collision-free, even though wireless signal transmission areas of the source nodes of the communication links are overlapped. However, since the number of channels in each wireless communication links are not so large that the performance of the wireless multihop network such as end-to-end transmission delay and throughput depends on the performance of the channel assignment algorithms, i.e., successful channel assignment ratio and required communication overhead.

There are two types of contentions and collisions in wireless multihop networks; among nodes in a wireless transmission route (intra-route) and among nodes in multiple wireless transmission routes (inter-route). If multiple wireless transmission routes are crossing or close together, inter-route contentions and collisions occur. In [1], flooding-based on-demand routing protocol for reduction of inter-route contentions and collisions has been proposed. A Number of multihop transmission routes in which each intermediate node is included is assigned to it as a node metric and one of wireless multihop transmission routes detected by a flooding of route request control messages is selected according to a route metric calculated by using the node metric of intermediate nodes along the routes. That is, a wireless transmission route in which its intermediate nodes are less shared with the other existing routes is selected. In [4], modification of wireless multihop transmission routes by replacement and/or addition of intermediate nodes has been proposed. This method is based on transmission power control in wireless nodes and each wireless node transmits data messages to its next-hop node by using the minimum transmission power to include the next-hop node in its transmission range. If an intermediate node detects high ratio of contentions and collisions, by replacement of an intermediate node to move the transmission range and/or by addition of an intermediate node to transmit data messages with lower transmission power, contentions and collisions are avoided or reduced. These approaches are under an assumption that only one communication channel is assigned to each wireless communication link in a wireless multihop network.

In [6], for wireless multihop networks in which multiple communication channels are available in each wireless communication link, a simple channel assignment algorithm for avoidance or reduction of inter-route contentions and collisions has been proposed. Each time a wireless multihop transmission route is detected by using an on-demand ad-hoc routing protocol, one of the communication channels is selected and the selected channel is assigned to all the wireless communication links in the detected wireless multihop transmission route. Even if two wireless multihop transmission routes are crossing or close together, there are no contentions and collisions between the routes if different communication channels are assigned to them. However, the problem of intra-route contentions and collisions is not solved. Since the same communication channel is assigned to all the wireless communication links along a wireless transmission route, a previous-hop and a next-hop nodes for each intermediate node are hidden terminals with each other.

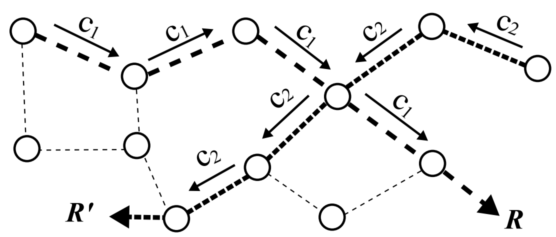

Figure 1: Route-Based Channel Assignment for Avoidance of Inter-Route Contentions and Collisions.

In [3], a link-based channel assignment algorithm has been proposed. That is, different communication channels are assigned to wireless communication links in a wireless multihop transmission route and it is possible to avoid or reduce inter-route and intra-route contentions and collisions by an adequate channel assignment algorithm as shown in Figure 2. For channel assignment to a wireless communication link $|N_pN_q\rangle$, all communication channels assigned to wireless communication links $|NN'\rangle$ where N is a 1-hop or 2-hop neighbor node of N_p are prohibited to avoid contentions and collisions or restricted to reduce them. Based on the restriction, various methods to select one communication channel from multiple candidate communication channels have been proposed and successful channel assignment ratio has been evaluated. However, since the restriction is independent of wireless multihop transmission routes, the channel assignment ratio becomes lower in environments with higher communication request frequence, i.e., with more wireless multihop transmission routes.

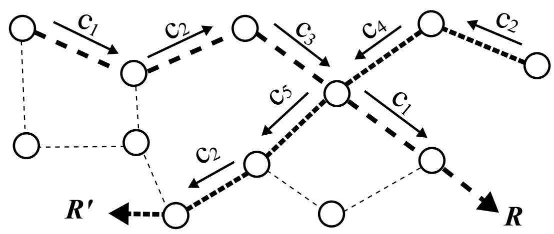

Figure 2: Link-Based Channel Assignment for Avoidance of Inter- and Intra-Route Contentions and Collisions.

3 Weaker Restrictions

For achieving higher channel assignment ratio, this section proposes a channel assignment algorithm with weaker restrictions than the conventional one. Here, in a wireless multihop transmission route $R = ||N_0 \ldots N_l\rangle\rangle$ from a source node N^s $(= N_0)$ to a destination node N^d $(= N_l)$, there are the following 4 requirements for channel assignment in each wireless communication link $|N_iN_{i+1}\rangle$ for avoidance of inter-route and intra-route contentions and collisions. Here, $NE_1(N_i)$ and $NE_2(N_i)$ represents sets of 1-hop and 2-hop neighbor nodes of N_i, respectively.

[Requirement 1]
For avoidance of contentions and collisions at N_i, communication channels already assigned to communication links $|NN_i\rangle$ from 1-hop neighbor node $N \in NE_1(N_i)$ of N_i to N_i are not assigned to $|N_iN_{i+1}\rangle$ $(0 \leq i < l)$ as shown in Figure 3.

[Requirement 2]
For avoidance of contentions and collisions at N_{i+1}, communication channels already assigned to communication links $|N_{i+1}N\rangle$ from N_{i+1} to 1-hop neighbor node $N \in NE_1(N_{i+1})$ of N_{i+1} are not assigned to $|N_iN_{i+1}\rangle$ $(0 \leq i < l)$ as shown in Figure 4.

[Requirement 3]
For avoidance of contentions and collisions at 1-hop neighbor node $N \in NE_1(N_i)$ of N_i *in another wireless multihop transmission route* R' due to the hidden terminal problem, communication channels already assigned to communication links $|N'N\rangle$ from 2-hop neighbor node

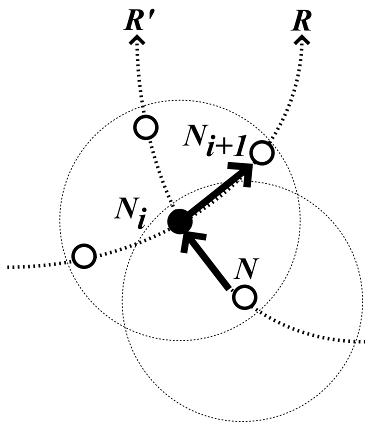

Figure 3: Requirement 1 for Channel Assignment.

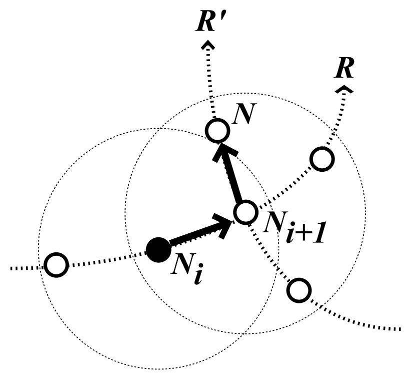

Figure 4: Requirement 2 for Channel Assignment.

N' of N_i to N are not assigned to $|N_iN_{i+1}\rangle$ $(0 \leq i < l)$ as shown in Figure 5.

[Requirement 4]
For avoidance of contentions and collisions at 1-hop neighbor node $N \in NE_1(N_{i+1})$ of N_{i+1} *in another wireless multihop transmission route* R' due to the hidden terminal problem, communication channels already assigned to communication links $|NN'\rangle$ from N to 2-hop neighbor node N' of N_{i+1} are not assigned to $|N_iN_{i+1}\rangle$ $(0 \leq i < l)$ as shown in Figure 6.

According to the above 4 requirements, for channel assignment to $|N_iN_{i+1}\rangle$, it is not required to restrict assignment of all communication channels already assigned to $|NN'\rangle$ where $N \in NE_1(N_i) \cup NE_2(N_i)$. Even if a communication channel c is assigned to $|NN'\rangle$, c can be assigned to $|N_iN_{i+1}\rangle$ if $N \notin NE_1(N_{i+1})$ and $N' \notin NE_1(N_i)$ since there are no contentions and collisions at any intermediate node as shown in Figure 7. Therefore the following weaker restriction on channel assignment is induced:

[Weaker Restriction]
Communication channel c is not allowed to be assigned to $|N_{i+1}\rangle$, if c has already assigned to another wireless communication link $|NN'\rangle$ where $N \in NE_1(N_{i+1})$ or $N' \in NE_1(N_i)$.

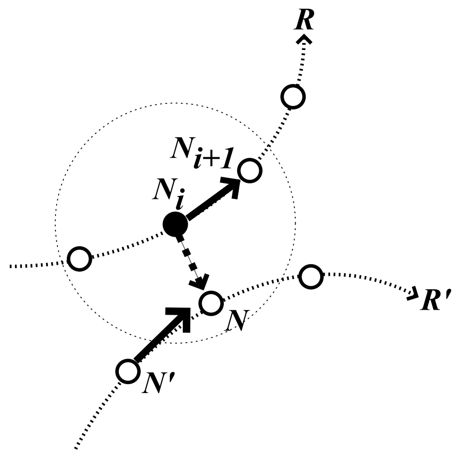

Figure 5: Requirement 3 for Channel Assignment.

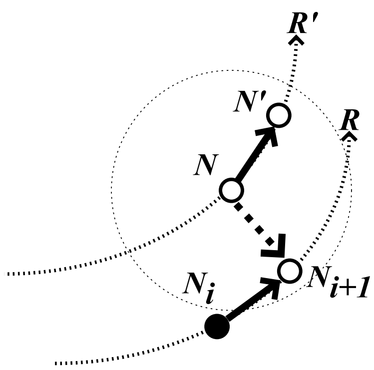

Figure 6: Requirement 4 for Channel Assignment.

4 Channel Assignment Protocol

4.1 Assigned Channel Management

Each time a wireless node N_i in $R = ||N_0 \ldots N_l\rangle\rangle$ assigns a communication channel c to a wireless communication link $|N_iN_{i+1}\rangle$, N_i should find c satisfying the restriction in the previous section. In order to verify the restriction, N_i is required to get the information about channels assigned to all wireless communication links issued from 1-hop and 2-hop neighbor nodes of N_i. However, for achieving channel assignment information from all 1-hop and 2-hop neighbors each time channel

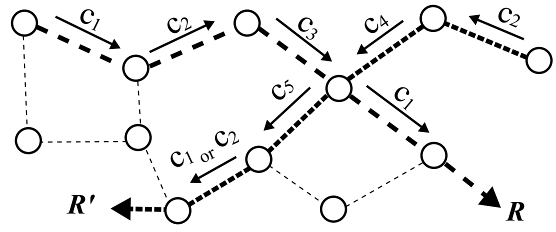

Figure 7: Link-Based Channel Assignment with Weaker Restrictions.

assignment to a wireless communication link is required, high communication and time overheads are required. For lower communication overhead and for shorter time duration before data message transmission, this paper proposes an assigned channel management method that when a communication channel c is assigned to a wireless communication link $|N_iN_{i+1}\rangle$, both N_i and N_{i+1} record the assignment.

For Requirement 1, communication channels assigned to $|NN_i\rangle$ are required. Since these communication channels are recorded in N_i, no control messages are required to be transmitted. For Requirement 2, communication channels assigned to $|N_{i+1}N\rangle$ are required and these communication channels are recorded in N_{i+1}. For Requirement 3, communication channels assigned to $|N'N\rangle$ where $N \in NE_1(N_i)$ are required and are recorded in N. Hence, for achieving the communication channels, N_i broadcasts a channel assignment request control message to its 1-hop neighbor nodes and these nodes return channel assignment reply control messages with assigned channels. By this request-reply protocol, N_i also achieves communication channels assigned to $|N_{i+1}N\rangle$ recorded in N_{i+1}. However, in order for N_i to achieve channel assignment information for Requirement 4, control message transmissions between N_i and 2-hop neighbors of N_i are required. This is because communication channels assigned to a wireless communication link $|NN'\rangle$ where $N \in NE_1(N_{i+1})$ is recorded in N and if N is out of wireless signal transmission range of N_i, $N \in NE_2(N_i)$ and $N \notin NE_1(N_i)$.

4.2 Backward-Type Channel Assignment

In order to solve the problem discussed in the previous subsection, this paper proposes a backward-type channel assignment method in which a communication channel is assigned to a wireless communication link nearer to a destination node earlier. Here, assigned communication channel to a wireless link $|N_iN_{i+1}\rangle$ is determined not by N_{i+1} but by N_i. Here, N_{i+1} detects communication channels satisfying Requirement 4 in $|N_iN_{i+1}\rangle$. Hence, channel assignment information in $N \in NE_1(N_{i+1})$ is required to be transmitted not to N_i but to N_{i+1}. A set of the detected channels which are candidates to be assigned to $|N_iN_{i+1}\rangle$ is notified to N_i. Then, N_i determines one of the communication channels in the set to assign to $|N_iN_{i+1}\rangle$ since N_i verifies satisfaction of Requirement 1–3 by gathering channel assignment information in $N \in NE_1(N_i)$. Therefore, in the proposed backward-type channel assignment method, each intermediate node along a wireless transmission route is required to gather channel assignment information from only its 1-hop neighbor nodes.

4.3 WR-B Protocol

We design a channel assignment protocol WR-B (Weaker Restriction and Backward-Direction) based on the restriction in the previous section. The proposed protocol works under an assumption that a wireless multihop transmission route has already been detected. In most of flooding-based ad-hoc routing protocols such as AODV[5] and DSR [2], a wireless multihop transmission route is detected in a destination node by receipt of a route request control message *Rreq* and the detected route is notified by unicast transmission of a route reply control message *Rrep*. As discussed in the previous subsections, a communication channel is assigned to each wireless communication link along a wireless multihop transmission route in the backward direction in our proposal. Hence, the route notification and the channel assignment is realized simultaneously and waiting time for channel assignment becomes shorter. WR-B channel assignment and release protocols are as follows.

[WR-B Channel Assignment Protocol]

(Destination Node N_l)

1) A destination node N_l broadcasts an assignment information request message *AIreq* to all neighbor node in the wireless signal transmission range of N_l.
2) On receipt of *AIreq* from N_l, each neighbor node N of N_l sends back an assignment information reply message *AIrep* to which a set $A_n(N)$ of communication channels assigned to wireless communication links $|NN_n\rangle$ and a set $A_p(N)$ of communication channels assigned to wireless communication links $|N_pN\rangle$ are piggybacked.
3) On receipt of all *AIrep*s, N_l calculates a set $A_c(N_l) = \cup_N A_n(N)$ containing communication channels which satisfy Requirement 4 for channel assignment in a wireless communication link $|N_{l-1}N_l\rangle$.
   - 3-1) If $A_c(N_l) \neq \emptyset$, N_l unicasts a channel assignment request message $Areq(A_c(N_l))$ to N_{l-1}.
   - 3-2) Otherwise, i.e., if $A_c(N_l) = \emptyset$, the channel assignment protocol terminates.
4) On receipt of $Anack(c_{l-1})$ from N_{l-1}, N_l releases c_{l-1} from $|N_{l-1}N_l\rangle$, i.e., $A_p(N_l) := A_p(N_l) - \{c_{l-1}\}$ and the channel assignment protocol terminates.

(Intermediate Node N_i)

1) On receipt of $Areq(A_c(N_{i+1}))$ from N_{i+1}, N_i broadcasts an assignment information request messages *AIreq* to all neighbor node in wireless signal transmission range of N_i.
2) On receipt of *AIreq* from N_i, each neighbor node N of N_i sends back an assignment information reply message *AIrep* to which a set $A_n(N)$ of communication channels assigned to wireless communication links $|NN_n\rangle$ and a set $A_p(N)$ of communication channels assigned to wireless communication links $|N_pN\rangle$

are piggybacked.

3) On receipt of all *AIreps*, N_i calculates a set $A_c(N_i)= A_c(N_{i+1}) \cap \overline{\cup_N A_p(N) \cup A_p(N_i)}$ containing communication channels which satisfy Requirements 1–4 for channel assignment in a wireless communication link $|N_i N_{i+1}\rangle$.
   3-1) If $A_c(N_i) \neq \emptyset$, N_i assigns one communication channel $c_i \in A_c(N_i)$ to $|N_i N_{i+1}\rangle$, i.e., $A_n(N_i) := A_n(N_i) \cup \{c_i\}$. Then, N_i unicasts a channel assignment reply message $Arep(c_i)$ to N_{i+1} and calculates a set $A_c(N_i)= \overline{\cup_N A_n(N)}$.
      3-1-1) If $A_c(N_i) \neq \emptyset$, N_i unicasts a channel assignment request message $Areq(A_c(N_i))$ to N_{i-1}.
      3-1-2) Otherwise, i.e., if $A_c(N_i) = \emptyset$, N_i releases c_i from $|N_i N_{i+1}\rangle$, i.e., $A_n(N_i) := A_n(N_i) - \{c_i\}$. Then, N_i unicasts a negative acknowledgement message $Anack(c_i)$ to N_{i+1}.
   3-2) Otherwise, i.e., if $A_c(N_i) = \emptyset$, N_i unicasts $Anack()$ to N_{i+1}.
4) On receipt of $Arep(c_{i-1})$ from N_{i-1}, N_i assigns c_{i-1} to $|N_{i-1} N_i\rangle$, i.e., $A_p(N_i) := A_p(N_i) \cup \{c_{i-1}\}$.
5) On receipt of $Anack(c_{i-1})$ from N_{i-1}, N_i releases c_{i-1} and c_i from $|N_{i-1} N_i\rangle$ and $|N_i N_{i+1}\rangle$, respectively, and unicasts $Anack(c_i)$ to N_{i+1}.

(Source Node N_0)

1) On receipt of $Areq(A_c(N_1))$ from N_1, a source node N_0 broadcasts an assignment information request messages *AIreq* to all neighbor node in wireless signal transmission range of N_0.
2) On receipt of *AIreq* from N_0, each neighbor node N of N_0 sends back an assignment information reply message *AIrep* to which a set $A_n(N)$ of communication channels assigned to wireless communication links $|N N_n\rangle$ and a set $A_p(N)$ of communication channels assigned to wireless communication links $|N_p N\rangle$ are piggybacked.
3) On receipt of all *AIreps*, N_0 calculates a set $A_c(N_0)= A_c(N_1) \cap \overline{\cup_N A_p(N) \cup A_p(N_0)}$ containing communication channels which satisfy Requirements 1–4 for channel assignment in a wireless communication link $|N_0 N_1\rangle$.
   3-1) If $A_c(N_0) \neq \emptyset$, N_0 assigns one communication channel $c_0 \in A_c(N_0)$ to $|N_0 N_1\rangle$, i.e., $A_n(N_0) := A_n(N_0) \cup \{c_0\}$. Then, N_0 unicasts a channel assignment reply message $Arep(c_0)$ to N_1.
   3-2) Otherwise, i.e., if $A_c(N_0) = \emptyset$, N_0 unicasts $Anack()$ to N_1.

[Channel Release Protocol]

(Source Node N_0)

1) A source node N_0 releases c_0 from $|N_0 N_1\rangle$, i.e., $A_n(N_0) := A_n(N_0) - \{c_0\}$, and unicasts a channel release request message $Relreq(c_0)$ to N_1.

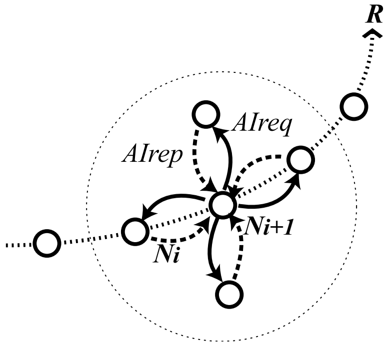

Figure 8: Gathering Channel Assignment Information of Neighbor Nodes to N_{i+1}.

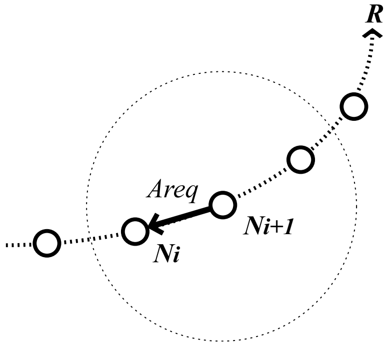

Figure 9: Notification of Channels Satisfying Requirement 4 to N_i.

(Intermediate Node N_i)

1) On receipt of $Relreq(c_{i-1})$ from N_{i-1}, an intermediate node N_i releases c_{i-1} from $|N_{i-1} N_i\rangle$, i.e., $A_n(N_i) := A_n(N_i) - \{c_{i-1}\}$, releases c_i from $|N_i N_{i+1}\rangle$, i.e., $A_p(N_i) := A_p(N_i) - \{c_i\}$, and unicasts $Relreq(c_i)$ to N_{i+1}.

(Destination Node N_l)

1) On receipt of $Relreq(c_{l-1})$ from N_{l-1}, a destination node N_l releases c_{l-1} from $|N_{l-1} N_l\rangle$, i.e. $A_n(N_i) := A_n(N_l) - \{c_{l-1}\}$.

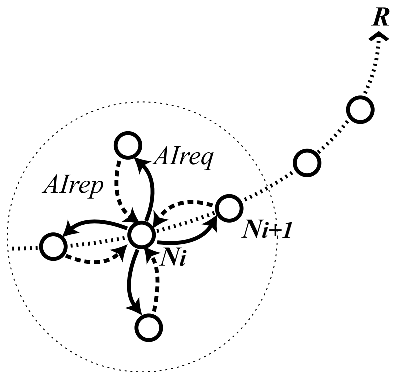

Figure 10: Gathering Channel Assignment Information of Neighbor Nodes to N_i.

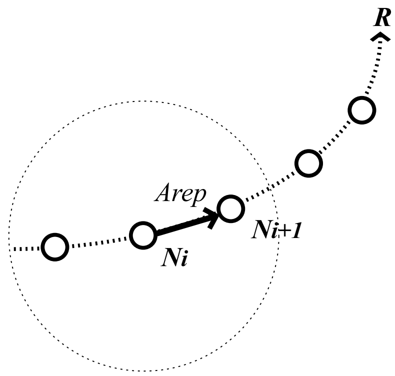

Figure 11: Notification of Channel Assigned to $|N_i N_{i+1}\rangle$ to N_{i+1}.

5 Evaluation

The performance of WR-B protocol is evaluated in simulation experiments. Here, successful channel assignment ratio is evaluated in comparison with the route-based channel assignment protocol (called RB protocol in this section)[6] in which one channel is assigned to all wireless communication links in a wireless multihop transmission route and the link-based route-independent channel assignment protocol (called LBRI protocol in this section)[3] in which different channels are assigned to wireless communication links in a wireless multihop transmission route and a communication channel different from those assigned to all 2-hop neighbor nodes are assigned to a wireless communication link.

In a 1000m 1000m square field, 500 wireless nodes with 80m wireless signal transmission range are distributed according to unique distribution randomness. 4, 6 and 8 communication channels are available in each wireless communication link. In WR-B and LBRI, one of candidate communication channels is randomly selected if multiple candidate channels are possible to be assigned to a wireless communication link. On the other hand in RB, a source wireless node randomly select one communication channel assigned to all wireless communication links in a wireless multihop transmission route. In environments with different numbers of wireless multihop transmission routes in which communication channels have been already assigned, successful channel assignment ratio in WR-B, RB and LBRI is evaluated as shown in Figures 12, 13 and 14.

The channel assignment ratio becomes lower as the numbers of existing wireless multihop transmission routes increases independently of the number of channels and the channel assignment protocols since communication channels satisfying all the requirements is reduced. In comparison with LBRI protocol, WR-B protocol achieves 17.8%, 12.9% and 2.65% higher channel assignment ratio with 4, 6 and 8 communication channels, respectively. This is because weaker restriction on channel assignment is applied than LBRI. On the other hand in comparison with RB protocol, WR-B protocol achieves 11.7% and 10.2% higher channel assignment ratio with 6 and 8 communication channels, respectively. However, with 4 communication channels, the channel assignment ratio in WR-B is 16.6% lower than in RB. This is because 4 communication channels are not enough for avoidance of intra-route contentions and collisions since at least 3 communication channels are required due to the hidden terminal problem. Therefore, except for the cases with too small numbers of communication channels, WR-B protocol achieves higher channel assignment ratio than the conventional protocols.

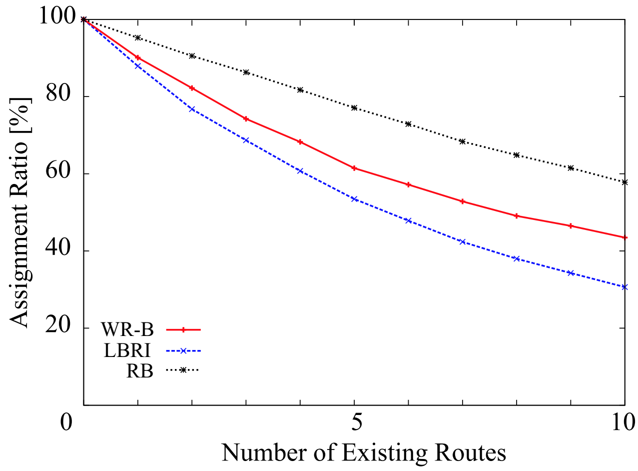

Figure 12: Channel Assignment Ratio with 4 Channels.

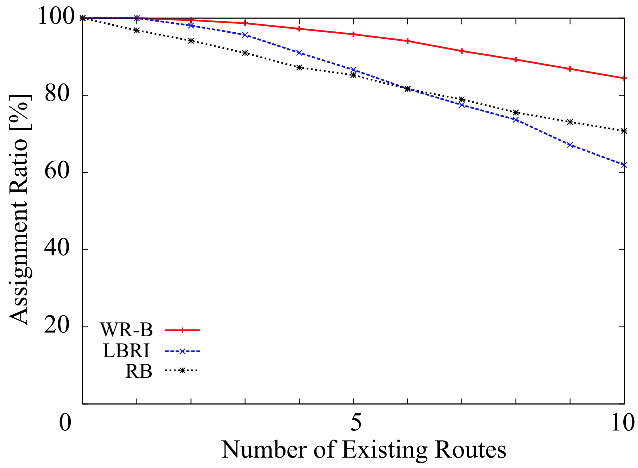

Figure 13: Channel Assignment Ratio with 6 Channels.

6 Concluding Remarks

This paper proposes a channel assignment algorithm for contention- and collision-free wireless multihop networks with higher assignment ratio. Communication channels are assigned in link-by-link manner and a weaker restriction on channel assignment than those in the conventional algorithms is introduced. For implementation of the algorithm with lower communication and time

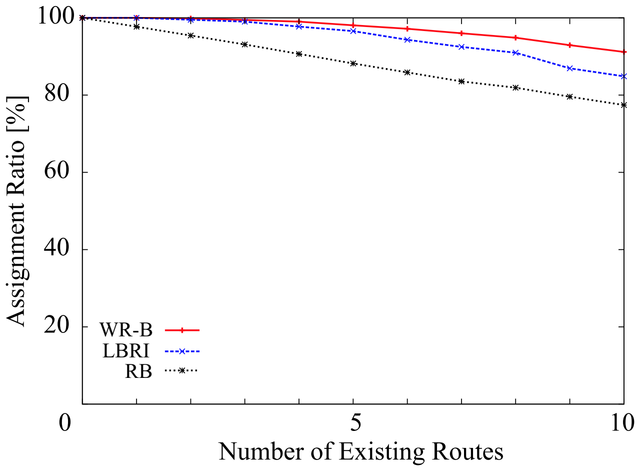

Figure 14: Channel Assignment Ratio with 8 Channels.

overhead, this paper proposes a backward-type channel assignment protocol and it achieves higher channel assignment ratio and higher throughput of data messages. The proposed protocol in this paper achieves contention- and collision-free wireless multihop networks with higher channel assignment ratio. Now, the authors are evaluating data message throughput.

The channel assignment ratio is not enough high in environments with high communication frequence and longer communication period, i.e. with many existing wireless multihop transmission routes. Hence, in our future work, the authors seek another channel assignment protocol for higher assignment ratio with less contentions and collisions.

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