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ループ探索を基礎とした無線マルチホップマルチキャスト通信への参加/離脱プロトコル

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MANET においてマルチキャスト配送木を構成するためには、漸次追加される受信無線ノードからマルチキャスト配送木に含まれる無線ノードのひとつへとマルチキャスト参加要求メッセージを配送することが必要である。MANET が双方向無線通信リンクのみではなく、片方向無線通信リンクをも含む場合には、参加要求メッセージが配送された無線マルチホップ配送経路の反転経路をデータメッセージ配送経路として用いることは必ずしも可能ではない。また、受信無線ノードがマルチキャスト配送木から離脱する際にはマルチキャスト配送木に含まれる無線通信リンクのみを用いてすべての離脱可能な中継無線ノードへ通知することも不可能である。本論文では、片方向無線通信リンクを含む無線マルチホップ配送経路を探索する LBSR プロトコルを拡張し、片方向無線通信リンクを含むマルチキャスト配送木を構成する際の参加/離脱プロトコルを提案する。

Multicast Tree Configuration Protocol in MANETs based on Looped Route Detections

Kazuhisa Suzuki[†1] and Hiroaki Higaki[†1]

In order to configure a multicast tree in a MANET (Mobile Ad-Hoc Network), each additional destination mobile computer transmits a joining request control message to one of the mobile computers already included in the tree. In case that the MANET consists of uni-directional (asymmetric) wireless links, a multihop transmission route along which the joining request control message is transmitted is not always available for data message transmission. In addition, in order for a destination mobile computer to leave from the multicast tree, the leaving request is also impossible to be transmitted along the tree. This paper proposes a novel multicast tree joining / leaving protocol which is an extension of LBSR, a unicast routing protocol supporting MANETs with uni-directional links. Here, since control messages for joining / leaving are transmitted along a local looped route, less communication overhead is required than the naive extension of the conventional method only supporting MANETs only with bi-directional wireless links.

1. Introduction

Due to development of mobile wireless computer technologies, research and development of mobile ad-hoc networks (MANETs) have been getting widely active. In MANETs, different from the conventional wireless networks supported by stationary wireless computers such as base stations, it is possible for wireless networks to be composed of only mobile wireless computers. Hence, it is expected for MANETs to play important roles for construction of temporary networks as infrastructures in conventions, disaster rescue and so on. In MANETs, data messages are transmitted along a wireless multihop transmission route from a source node to a destination one with help of forwarding by multiple intermediate nodes. Thus, lower power consumption, higher connectivity (availability) and higher throughput of data messages by avoidance of collisions and contentions are expected. Most of the proposed communication methods have been designed for MANETs with only bi-directional wireless communication links between wireless nodes. However, due to differences of characteristics of wireless communication devices and differences of battery capacities in wireless nodes and due to transmission power control in wireless nodes for certain purposes, there may be uni-directional wireless links between wireless nodes. Usually, in the conventional communication methods for MANETs, such uni-directional wireless links are ignored, i.e. no data and control messages are transmitted along the uni-directional wireless links. A few communication protocols have been designed under an assumption that wireless networks contain both bi- and uni-directional wireless links and have achieved higher performance such as higher connectivity and shorter transmission delay by transmission of data messages along a wireless multihop transmission route consisting of both bi- and uni-directional wireless links.

On the other hand, in applications such as information distribution and radio broadcasting in disaster rescue and information advertisement in conventions, data messages are required to be transmitted to multiple destination wireless nodes. Here, for lower communication overhead, multicast communication protocols are required to be applied since each intermediate wireless node transmits each data message only once. There are mainly two multicast communication techniques based on multicast transmission trees and multicast transmission meshes. In a multicast transmission tree, a source wireless node is a root node N^s and multiple destination wireless nodes N_i^d are leaves or intermediate nodes. A multicast identification is given to all wireless nodes in a

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multicast tree and N^s transmits data messages destined to the multicast identification as shown in figure 1.a. Generally, in a multicast transmission service, data messages are required to be transmitted in one-way from N^s to each N_i^d. Therefore, it is possible for a multicast tree to contain uni-directional wireless links from a parent node to a child node.

A multicast tree is configured by adding destination wireless nodes one by one. In order to join the multicast tree, i.e. to receive data messages from a source wireless node N^s, it is required for a destination wireless node N_i^d to transmit a joining request message to a certain wireless node N in the multicast tree along a wireless multihop transmission route and to connect itself to the tree as shown in figure 1.b. In the conventional methods, a reverse multihop transmission route of a multihop transmission route along which a joining request message is transmitted from N_i^d to N is used for transmission of data messages since the route consists of only bi-directional wireless links. However, if a MANET contains uni-directional wireless links, the reverse multihop transmission route is not always used for data message transmissions since the joining request message may be transmitted through uni-directional wireless links. A method with multiple floodings of control messages as in DSR [1] which is a unicast routing protocol supporting a wireless multihop transmission route with uni-directional wireless links is one of the solutions; however, it requires much higher communication overhead. The authors have been proposed a unicast routing protocol LBSR [2] which detects a unicast wireless multihop transmission route including uni-directional wireless multihop transmission route with lower communication overhead. Based on LBSR, this paper proposes joining and leaving methods for wireless multihop multicast communication in wireless multihop networks such as wireless ad-hoc networks, sensor networks and mesh networks.

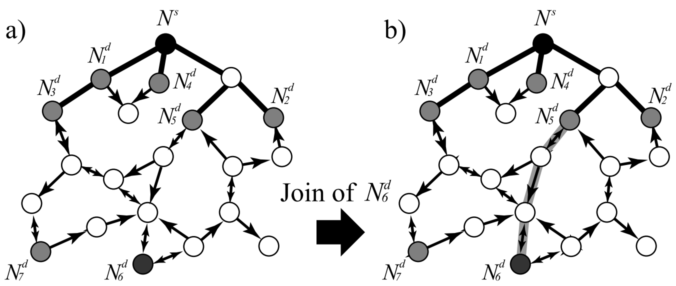

図 1　マルチキャスト配送木
Fig. 1　Multicast Transmission Tree.

2. Related Works

2.1 Ad-Hoc Multicast Communication

A wireless ad-hoc network $\langle \mathcal{N}, \mathcal{L} \rangle$ is configured a set $\mathcal{N}$ of wireless nodes N_i and a set $\mathcal{L}$ of wireless links $|N_iN_j\rangle$ from N_i to N_j. Here, a wireless link $|N_iN_j\rangle$ is available if a wireless node N_j is in a wireless signal transmission range of another wireless node N_i. If $|N_iN_j\rangle \in \mathcal{L}$ and $|N_jN_i\rangle \in \mathcal{L}$, N_i and N_j are connected by a bi-directional communication link $\langle N_iN_j\rangle$. On the other hand, if $|N_iN_j\rangle \in \mathcal{L}$ and $|N_jN_i\rangle \notin \mathcal{L}$, there is a uni-directional communication link $|N_iN_j\rangle$ from N_i to N_j.

In an ad-hoc network, if a destination wireless node N^d is not included in a wireless signal transmission range of a source wireless node N^s, a wireless multihop transmission route $R = ||N_0(= N^s) \dots N_n(= N^d)\rangle\rangle$ is configured from N^s to N^d with help of intermediate wireless nodes N_i and data messages are transmitted along R. R is also a sequence of wireless links $|N_iN_{i+1}\rangle$ $(0 \leq i < n)$. Each intermediate wireless node N_i $(0 < i < n)$ receives data messages from its previous-hop wireless node N_{i-1} and transmits (forwards) them to its next-hop wireless node N_{i+1}.

In a multicast transmission service, data messages are transmitted from a source wireless node N^s to multiple destination wireless node N_i^d. Let RS be a set of destination wireless nodes, i.e. $RS := \{N_i^d\}$. In order to transmit data messages from N^s to each N_i^d in RS, a wireless multihop transmission route $R_i = ||N^s \dots N_i^d\rangle\rangle$ is required to be detected and configured. However, if each R_i is configured independently of the others, there are the following problems:

- Some intermediate wireless nodes may be included in multiple wireless multihop transmission routes.
- Pairs of intermediate wireless nodes included in their wireless signal transmission ranges each other are increased.

An intermediate wireless node included in multiple wireless multihop transmission routes transmits data messages multiple times to its next-hop wireless nodes in the routes. Hence, the battery capacity in the node is wasted. Increase of the pairs of wireless nodes included in their wireless signal transmission ranges each other also increases collisions and contentions between these wireless nodes and causes higher data message loss ratio, longer transmission delay and lower data message throughput. Since wireless communication is based on broadcast in the wireless signal transmission range, multicast data message is forwarded to all the next-hop wireless nodes of an intermediate wireless node by only one time broadcast of the data message.

In order to solve the problems, a multicast tree is widely used. Here, a rooted-tree in which a source wireless node N^s is the root, multiple destination nodes are leaves or intermediate node and additional intermediate wireless nodes are also included for wireless multihop transmission of data messages is configured and data messages are transmitted along the links in the tree. Each intermediate wireless node receives a data message from its parent wireless node and forwards it to all its child wireless nodes by only one broadcast transmission. Hence, multicast transmissions of data messages are realized with lower communication overhead.

2.2 Joining and Leaving Multicast Tree

Requirements for configuration methods of a multicast tree depend on whether a set RS of destination nodes has been already determined or not. This paper assumes that RS has not yet been determined before the beginning of the multicast service. That is, each destination wireless node N_i^d autonomously determines to join a multicast group with a multicast identification and receives data messages transmitted from a source wireless node N^s along a multicast tree for the multicast service. Here, a multicast tree *Tree* for data message transmissions from a source wireless node N^s to multiple destination wireless nodes in $RS(\not\ni N_i^d)$ has been configured. Now, for joining *Tree* of an additional destination wireless node N_i^d, i.e. for configuring an updated multicast tree *Tree*′ as $RS' := RS \cup \{N_i^d\}$ and realizing data message transmissions to N_i^d, there are the following two requirements:

[Requirements for Joining Multicast Tree]

R1: A joining request control message is transmitted from N_i^d to one of the wireless nodes N in *Tree*.

R2: A wireless multihop transmission route $||N' \ldots N_i^d\rangle\rangle$ from one of the wireless nodes N' in *Tree* to N_i^d is detected and configured.

In [3], the above two requirements are satisfied by diffusing a multicast joining request control message *Mreq* with a multicast ID by a flooding though all wireless links are assumed to be bi-directional, i.e. it is assumed that data messages are transmitted only along bi-directional wireless links as shown in figure 2.a. A flooding of *Mreq* from N_i^d progresses by continuous broadcasts of *Mreq* on the first receipt of *Mreq* in wireless nodes out of *Tree*. By receipt of *Mreq* in a wireless node N in *Tree*, the requirement R1 is satisfied.

Since all wireless links are assumed to be bi-directional, due to $N' := N$, a reverse wireless multihop transmission route $||N \ldots N_i^d\rangle\rangle$ of a wireless multihop transmission route $||N_i^d \ldots N\rangle\rangle$ along which *Mreq* is transmitted from N_i^d to N is available for transmissions of multicast data messages. Thus, a joining reply control message *Mrep* is transmitted from N to N_i^d along this reverse route as shown in figure 2.b. On receipt of the *Mrep*, N_i^d detects a candidate wireless multihop transmission route for multicast data messages. However, since *Mreq* is diffused by a flooding, multiple wireless nodes in *Tree* may receive *Mreq* messages and multiple *Mrep* may be sent back to N_i^d along different wireless multihop transmission routes. Now, there are multiple candidates wireless multihop transmission routes for multicast data messages to N_i^d. Thus, N_i^d selects one of the candidate routes which are detected by receipt of *Mrep* messages before a timer expiration. In [3], summation of load in all the intermediate wireless nodes along the detected wireless multihop transmission routes are evaluated and a route with the minimum summation of load is selected. Then, a joining confirmation control message *Mconf* is unicasted along the selected wireless multihop transmission route from N_i^d and each intermediate wireless node stores its next-hop node in its routing table for multicast data message transmissions with the multicast identification. Therefore, the requirement R2 is satisfied.

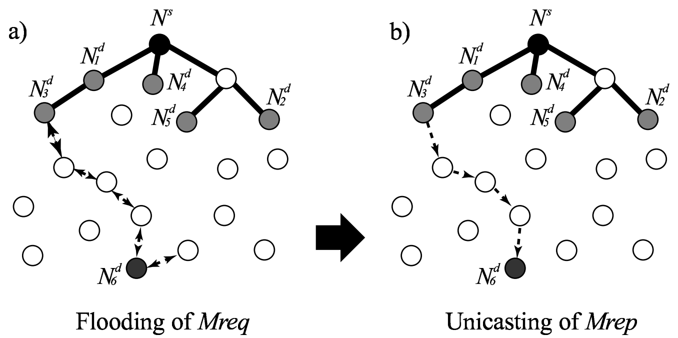

図 2 双方向無線通信リンクのみを用いる従来手法によるマルチキャスト通信への参加
Fig. 2 Conventional Joining Method based on Bi-Directional Links.

On the other hand, the following is required for a wireless node $N_i^d \in RS$ to leave a multicast tree *Tree* whose source wireless node is N^s and a set of destination nodes is RS and to configure an updated multicast tree *Tree*′ where $RS' := RS - \{N_i^d\}$.

[Requirement for Leaving Multicast Tree]

R3: A leaving request control message from N_i^d is transmitted to all wireless nodes in *Tree* whose descendant destination wireless node is only N_i^d.

In [3] where all wireless links are assumed to be bi-directional, R3 is satisfied only by transmitting a *MLreq* message with a multicast identification from N_i^d to its ancestor wireless nodes along *Tree*. There are the following three cases in an ancestor wireless nodes receiving the *MLreq* message:

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a) An intermediate wireless node where N_i^d is its unique descendant destination wireless node.
b) An intermediate wireless node which has other descendant destination wireless nodes than N_i^d.
c) Another destination wireless node.

Only in case a), the ancestor wireless node also leaves the multicast tree and it is possible for its ancestor wireless nodes to leave the multicast tree. Otherwise, i.e. in cases b) and c), the ancestor wireless node is required to be kept in the multicast tree for transmissions of data messages to other destination wireless nodes and it is also impossible for its ancestor wireless nodes to leave the multicast tree. Therefore, for a leaving protocol, each intermediate wireless node is required to keep the identifications of its child wireless nodes.

2.3 Joining Multicast Tree with Uni-Directional Links

In [3], multicast data messages are transmitted only through bi-directional wireless links as shown in figure 2.a. However, in multicast data message transmissions in both wired and wireless networks, hop-by-hop acknowledgement for data message receipt is not usually applied between each intermediate wireless node N^p and its next-hop one N^c. Thus, multicast data messages are transmitted through a wireless link $|N^pN^c\rangle$ and no acknowledgement messages are transmitted through a wireless link $|N^cN^p\rangle$. Especially in a wireless networks, since all next-hop wireless nodes of an intermediate wireless node in a multicast tree are surely included in its wireless signal transmission range, it is only required for the intermediate wireless node to broadcast the data messages with the multicast identification. Thus, shorter transmission delay and higher throughput in the multicast transmission service are achieved. Therefore, in a multicast transmission tree, only uni-directional wireless links from parent nodes to their child nodes are required and bi-directional wireless links are not always required for data message transmissions.

In addition, in configuration of multicast trees containing uni-directional wireless links, there are following merits in comparison with multicast trees only with bi-directional wireless links:

- Higher connectivity in multicast transmission services is achieved. In the conventional methods, it is possible for destination wireless nodes to join a multicast transmission tree only if it can detects a wireless multihop transmission route from the source wireless nodes with only bi-directional wireless links.
- Shorter transmission delay of multicast data messages is expected. By including uni-directional wireless links in a multicast tree, i.e. in a wireless multihop transmission route from the source wireless node, a shorter multicast transmission routes can be applied for multicast data message transmissions.

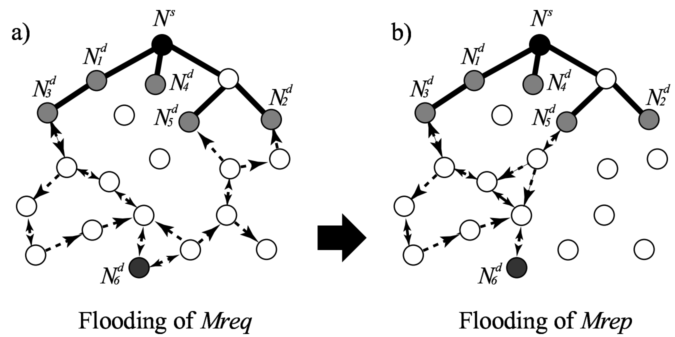

図 3 従来手法の拡張による片方向無線通信リンクをも用いたマルチキャスト通信への参加
Fig. 3 Multicast Tree Configuration by Naive Extension of Conventional Method.

In order to realize a multicast transmission tree including uni-directional wireless links, the joining and leaving protocol proposed in [3] is not applied. This is because the reverse wireless multihop transmission route $||N \dots N_i^d\rangle\rangle$ of a wireless multihop transmission route $||N_i^d \dots N\rangle\rangle$ detected by multihop transmission of *Mreq* from N_i^d to N is not used for multicast data message transmission since uni-directional wireless links might be included in $||N_i^d \dots N\rangle\rangle$. Hence, a wireless multihop transmission route $||N \dots N_i^d\rangle\rangle$ for data message transmissions from N to N_i^d is required to be detected and configured. As mentioned in [2], one of the naive methods is applying floodings of *Mrep* messages which has been adopted in an extension of DSR for supporting uni-directional wireless links. However, according to the method in [3], the *Mreq* messages from N_i^d are received by multiple wireless nodes N in *Tree* and each N is required to initiate a flooding of a *Mrep* message since it is not always possible to detect a wireless multihop transmission route $||N \dots N_i^d\rangle\rangle$ from each N for data message transmissions from N to N_i^d. Therefore, totally $n+1$ floodings of control messages, i.e. one flooding of an *Mreq* message and n floodings of *Mrep* messages, are required in the worst cases where n wireless nodes are included in a multicast transmission tree *Tree* (figure 3).

3. Proposal

3.1 LBSR

As discussed in subsection 2.3, a naive extension of the method in [3] requires $n+1$ floodings of control messages for an additional destination wireless node to join an existing multicast transmission tree consisting n wireless node. This is because the requirements R1 and R2 are independently satisfied by transmissions of *Mreq* control messages and *Mrep* control messages in the joining protocol. This section proposes a novel method to solve this problem by extension of LBSR ad-hoc routing protocol [2].

In LBSR, for achieving a wireless multihop transmission route from N^s to N^d which may contains uni-directional wireless links, a looped wireless multihop transmission route containing both N^s and N^d is detected by combination of only one flooding and some unicast transmissions of control messages. This subsection shows an overview of LBSR protocol.

A source wireless node N^s first initiates a flooding of a looped route request control message *Lreq*. The *Lreq* message is once broadcasted by all the wireless nodes to which N^s is wireless multihop reachable. Then, one of the following two results is achieved for each copies of the *Lreq* control message:

- *Lreq* reaches to N^s and a looped wireless multihop transmission route including N^s is detected.
- *Lreq* is received by a wireless nodes which has already broadcasted the *Lreq* message.

On receipt of the *Lreq* message, N^s detects a looped wireless multihop transmission route and initiates unicast transmission of a looped route confirmation message *Lconf* along the detected looped route as shown in figure 2.b. During this unicast transmission, on receipt of the *Lconf* message, a wireless node in the detected looped route piggies back *Lreq* message received after its broadcast of *Lreq* to the *Lconf* message and also forward it to its next-hop wireless node along the detected looped route. Thus, the piggybacked *Lreq* message reaches N^s and another looped route containing N^s is detected. Then, a *Lconf* control message is transmitted along the newly detected looped route for detection of other looped route. By repetition of this procedure, a looped wireless multihop transmission route containing both N^s and N^d is detected, i.e. a wireless multihop transmission route from N^s to N^d and another wireless multihop transmission route from N^d to N^s are detected by N^s simultaneously[⋆1].

3.2 Joining Protocol by Extension of LBSR

This subsection shows a protocol for joining multicast transmission tree by extension of LBSR protocol explained in the previous subsection. Here, an additional destination wireless node N_i^d requests to join an already existing multicast transmission tree and the tree is extended as shown in figure 4. That is, by applying an extended LBSR protocol explained in this subsection, a joining request control message *Mreq* is transmitted and a looped wireless multihop transmission route containing N_i^d and one of the wireless nodes included in the existing transmission tree *Tree* is detected. Hence, the requirements R1 and R2 are simultaneously satisfied for reduction of communication overhead.

Different from the LBSR which requires for two wireless nodes N^s and N^d to be included in a looped wireless multihop transmission route, the joining protocol requires to detect a looped wireless multihop transmission route containing N_i^d and any one of the wireless nodes in *Tree*. Thus, the *Mreq* control message flooded in the proposed joining protocol carries not a wireless node identification in the *Lreq* message in the original LBSR but a multicast identification assigned to the multicast transmission tree which N_i^d joins. In addition, *Mreq* carries a flag which shows whether the *Mreq* has been broadcasted by a wireless node included in *Tree*. Initially, i.e. at the beginning of the flooding of *Mreq* in N_i^d, *Detected* := *False*. Each wireless node out of *Tree* broadcasts *Mreq* messages without modification on the *Detected* flag. On the other hand, wireless nodes in *Tree* broadcasts *Mreq* message after substitution *Detected* := *True*. If N_i^d receives a *Mreq* message which is only flooded or is piggied back to a *Mconf* message whose *Detected* flag is *False*, the *Mreq* message is transmitted along a looped wireless multihop transmission route which contains only wireless nodes out of *Tree*. Otherwise, if the received *Mreq* message contains a *Detected* flag equals to *True*, at least one wireless node in *Tree* is included in the detected looped wireless multihop transmission route.

Since the *Mreq* message is flooded and N_i^d may transmits multiple *Mconf* messages along multiple looped wireless multihop transmission routes simultaneously, it is possible for N_i^d to detect multiple looped wireless transmission route including one of the wireless node in *Tree*. This means that even after joining the multicast tree, the joining protocol does not terminate and control messages are continuously transmitted in a wireless multihop network. In order to reduce the wasted consumption of wireless network resources, N_i^d initiates transmission of *Mconf* control message after receipt of *Mreq* message with *Detected* = *True* only once. Before receipt of *Mreq* message with *Detected* = *True*, M_i^d continues to initiate unicast transmissions of *Mconf* messages after receipt of *Mreq* messages with *Detected* = *False*. After the transmission of the *Mconf* control message after receipt of the *Mreq* message with *Detected* = *True*, N_i^d never initiates transmissions of *Mconf* messages even if *Detected* = *False* in received *Mreq* messages. This is realized since all unicast transmissions of *Mconf* messages are initiated in N_i^d. By introduction of the above restriction on the transmission of *Mconf* messages, communication overhead for joining a multicast transmission tree is realized.

3.3 Leaving Protocol based on Looped Route

For a destination wireless node to leave a multicast transmission tree *Tree*, a leaving

⋆1 In [2], broadcasts of *Lreq* and unicasts of *Lconf* are parallel and required synchronization among them is also realized.

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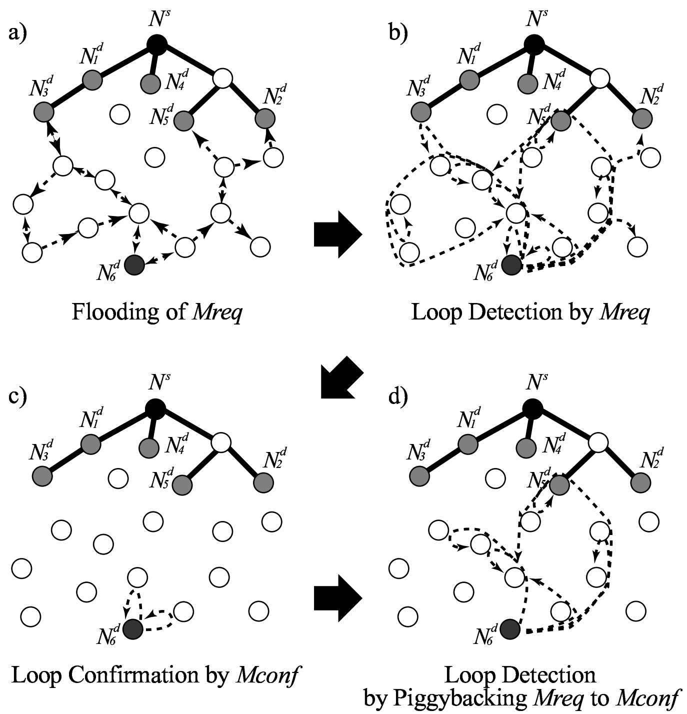

図 4 LBSR の拡張によるマルチキャスト通信への参加手法
Fig. 4 Joining Protocol by Extension of LBSR.

request control message *MLreq* is required to be transmitted to its ancestor wireless node if the destination node is a leaf node in *Tree*. As discussed in subsection 2.2, intermediate wireless nodes where N_i^d is the only its descendant destination wireless node is also allowed to leave *Tree* when N_i^d leave *Tree*. On the other hand, intermediate wireless nodes which has different descendant destination wireless nodes from N_i^d cannot leave *Tree* and are required to be in *Tree*.

If a multicast transmission tree *Tree* is configured only by bi-directional wireless links, N_i^d is only required to transmit an *MLreq* control message to its parent wireless node. On receipt of the *MLreq* control message, the parent node transmits the *MLreq* control message to its parent wireless node and leave *Tree* if N_i^d is the unique descendant destination wireless node. Otherwise, i.e. the parent node itself is a destination node or has another descendant destination wireless nodes, it does not forward the *MLreq* control message to its parent wireless node. On the other hand, if a multicast transmission tree contains uni-directional wireless links, N_i^d and/or its ancestor intermediate wireless nodes are not always possible to transmit *MLreq* control message to their parent nodes. Hence, it is possible for some intermediate wireless nodes in a multicast transmission tree *Tree* not to be allowed to leave *Tree* even though it has already been not required to forward data messages in *Tree*.

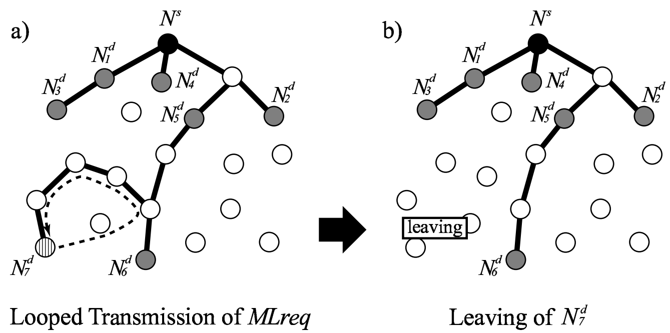

図 5 *MLreq* のループ経路配送による中継無線ノードの離脱
Fig. 5 Leaving Multicast Transmission Tree by Looped Transmission of *MLreq*.

In order to solve this problem, this subsection proposes a protocol for leaving a multicast transmission tree of a destination wireless node N_i^d in which a leaving request control message *MLreq* is transmitted along a looped route along which a *Mconf* message is transmitted in the procedure for joining the multicast transmission tree. All the intermediate wireless nodes which have been added to the multicast transmission tree *Tree* in joining *Tree* of N_i^d are included in a looped wireless multihop transmission route along which *Mconf* message is transmitted. In addition, a sequence of wireless nodes included in the looped wireless transmission route is a wireless multihop transmission route along which an *Mconf* message is transmitted in the joining protocol for N_i^d and is achieved by N_i^d. Thus, as shown in figure 5, *MLreq* is transmitted along the looped wireless multihop transmission route from N_i^d to N_i^d and all intermediate nodes in this looped route which is not required to forward data messages in the multicast transmission tree any more also leave the multicast transmission tree.

During wireless multihop transmission of the *MLreq*, an intermediate wireless node which has different descendant destination wireless nodes from N_i^d forwards *MLreq* but does not leave the multicast transmission tree *Tree* and continues transmissions of data

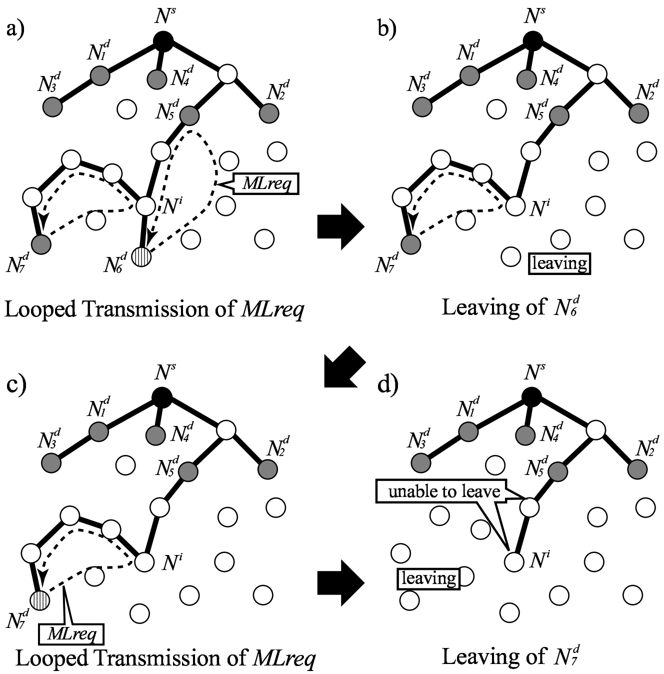

図 6 離脱不能中継無線ノードの発生
Fig. 6 Intermediate Wireless Node not Allowed to Leave Multicast Tree.

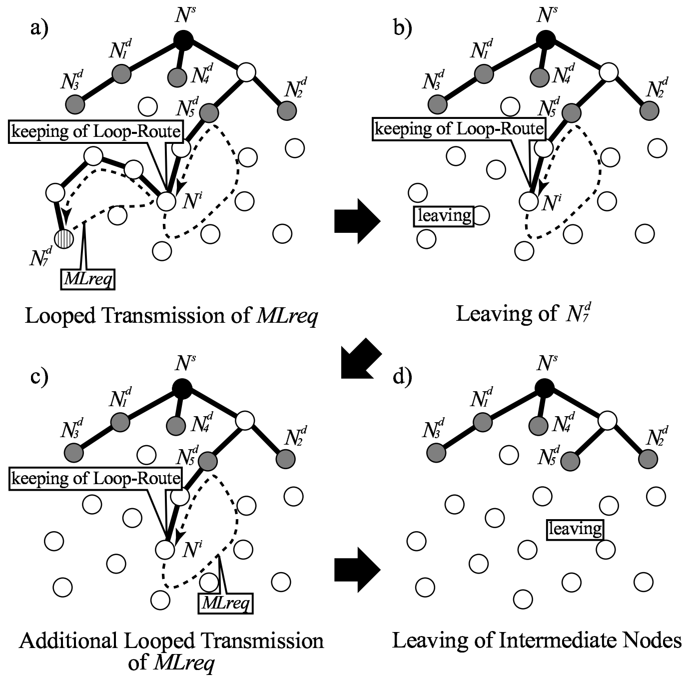

図 7 経路情報委譲による離脱不能無線ノード問題の解決
Fig. 7 Delegation of Looped Route Information.

messages in *Tree*. Here, there is another problem that when the unique descendant destination wireless node N_i^d of a wireless node N^i leaves *Tree* and an *MLreq* control message is transmitted along a looped wireless multihop transmission route along which an *Mconf* message is transmitted, N^i cannot leave *Tree* if its parent wireless node is not included in the looped route as shown in figure 6.

For solving this problem, it is required for all the descendant wireless nodes of N^i to transmits a leaving request control message to their parent node for leaving *Tree*. Thus, in our proposed protocol, when N^i receives a leaving request control message *MLreq* from one of the descendant destination wireless nodes and has other descendant destination wireless nodes, N^i holds a sequence of identifications of the wireless nodes in the looped wireless multihop transmission route along which the *MLreq* message is transmitted. Then, when N^i receives another *MLreq* control message for its unique descendant destination wireless node to leave the multicast transmission tree, N^i not only forward the received *MLreq* message but also initiates looped transmission of another *MLreq* message along the sequence of the wireless nodes held by N^i for leaving the tree of N^i as shown in figure 7. Since this looped route always contains the parents wireless node of N^i, the problem that N^i cannot leave the tree is solved. Such looped transmission of *MLreq* initiated by an intermediate wireless node, i.e. not by a destination wireless node, can be applied recursively.

4. Performance Evaluation

In this section, communication overhead required for configuration of multicast transmission tree, i.e. for joining and leaving the multicast transmission tree of a destination wireless node is evaluated in simulation experiments. Here, the overhead in our pro-

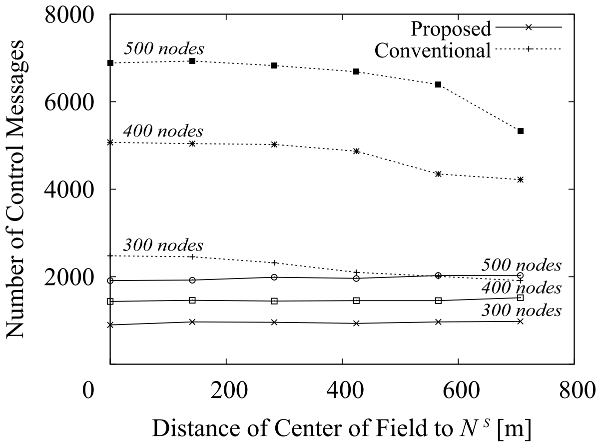

図 8　ノード参加に要する制御メッセージ数
Fig. 8　Communication Overhead for Joining.

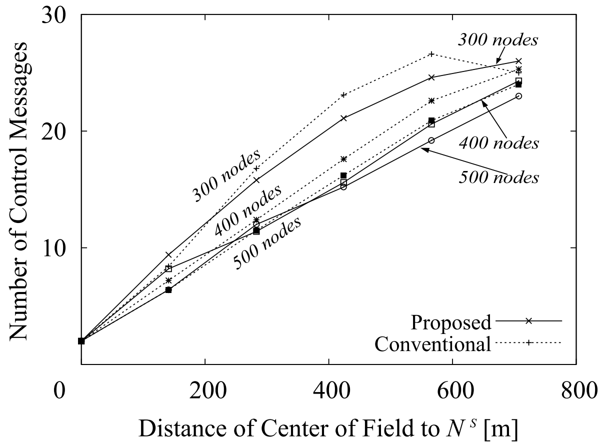

図 9　ノード離脱に要する制御メッセージ数
Fig. 9　Communication Overhead for Leaving.

posed protocol is compared to the naive extension of the method in [3] in which $n+1$ floodings of control messages are required for joining where n is the number of wireless nodes included in the multicast transmission tree.

300–500 wireless nodes stationary in the simulation experiments are distributed in a $1000m \times 1000m$ square field according to a unique distribution randomness. A wireless signal transmission distance of a wireless node is distributed according to the normal distribution whose average is $80m$ and standard deviation is $5m$. Before evaluation of communication overhead, a multicast transmission tree with 5–30 wireless nodes is configured and 10 randomly selected wireless nodes are added to the tree. Figure 8 shows the number of control messages transmitted for joining. The numbers of required control messages do not depend on locations of the existing multicast transmission tree in the field and depends on the number (density) of wireless nodes. In any cases, the proposed protocol requires only 50–70% control messages to be transmitted. In addition, figure 9 shows the number of control messages required for leaving the multicast transmission tree of a destination wireless node. Though in the proposed protocol, control messages are required to be transmitted along a looped route, the communication overhead is almost the same as in the conventional method.

5. Conclusion

This paper proposes a multicast tree configuration protocol, i.e. protocols for joining and leaving a multicast transmission tree of a wireless node by extension of LBSR ad-hoc routing protocol which has been designed for unicast routing with uni-directional wireless links. The results of simulation experiments show that the proposed joining protocol reduces the communication overhead and leaving protocol requires almost the same communication overhead as the conventional method.

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