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RFID Multi-hop Relay Algorithms with Active Relay Tags in Tag-Talks-First Mode

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Abstract

Internet of Things (IoT) has attracted much attention today. As the key component of IoT, the Radio Frequency Identification (RFID) network has been growing in usage. An RFID network is composed of a backend system (including the database), one or more readers, and several RFID tags. Most of the RFIT tags cannot transmit signals actively, except the active RFID tags. The active RFID tags may gather information from sensors and store the information for later delivery to the reader. To extend the coverage of the RFID network, some RFID multi-hop relay systems (using active RFID tag as relay tags) have been proposed. They are all designed in Reader Talks First (RTF) mode. That means multi-hop connections may be built up only when the reader queries and the tags response. On the contrary, in "Tag Talks First (TTF)" mode, an active tag cannot report anything to the system if it cannot find an available reader in its sense area. It may occur when the reader is located out of the sense area of the tag, or the reader is out of service (but the tag still needs to find out another reader to join in the RFID network). If these active tags are connection-lost from the system, some emergence messages may be lost. In this paper, we propose two multi-hop relay algorithms used in TTF mode, which are designed for Free2move and 802.15.4 standard respectively. Simulation results show that with the help of the proposed algorithms, the loss performance in TTF mode is improved a lot. Besides, the energy performance and delay performance is also improved compared to not using multi-hop relay algorithms in TTF mode, but use periodical data collection in RTF modes instead.

Keywords: Internet of Things, RFID, active tag, multi-hop relay

1 Introduction

Internet of Things (IoT) is rapidly gaining ground nowadays. The key component of IoT is the Radio Frequency IDentification (RFID) system. An RFID system is composed of a backend system (including the database), one or more readers, and several RFID tags. A reader can collect the data stored in tags. As for the tags, they can be divided into three categories: passive tags, semi-passive tags and active tags. Passive tags have no power source of their own. They obtain energy from the signal of the reader. Semi-passive tags have power sources which only power the microchip while receiving the signal from readers. Both of the passive tags and semi-passive tags are unable to transmit a signal to the reader actively. On the contrary, active tags have on-board power source and can transmit signals actively.

Commonly, there are two working modes for the communication between an active tag and the reader: the Reader Talks First (RTF) mode and the Tag Talks First (TTF) mode. In the RTF mode, the reader sends queries first and then the tags reacts; while in the TTF mode, the active tags send messages actively and presents rather independently of the reader.

Traditionally, in order to join in an RFID network, an active tag should be located in the interrogator area of a reader. However, there are some cases that direct communication between the reader and a tag cannot be built up. For example, a tag may be located out of the sense area of the reader or in dead-zone [8] where the RF of the reader cannot reach. Generally, these tags will be treated as connection-lost from the network. To save these connection-lost tags, some multi-hop relay RFID networks are proposed [8, 5]. In these algorithms, the active tags join into routing and help to build up multi-hop relay paths.

However, all of those proposed algorithms are designed for RTF mode only. They aim at helping the reader collect information from the tags. To the best of our knowledge, there is no algorithm proposed for saving connection-lost active tags in TTF mode. Nevertheless, it is important for some active tags that they can always report exceptions to the RFID system. For example, an active tag may cooperate with some sensors to monitor fire, and it is expected to send alarm message to the system in case of fire. When the reader close to the tag is unavailable when a fire occurs, the tag still needs to report the fire to the system. In this case, the tag may send the alarm message to a nearby reader in the same network, which may locate a little far away from it. To achieve this goal, multi-hop relay mechanisms designed for TTF mode are needed.

In this paper, we propose two multi-hop relay mechanisms. They are designed for Free2move protocol and IEEE 802.15.4 standard respectively. This paper is constructed as follows: Section 2 introduces some related works. In Section 3, we describe the proposed algorithms. Section 4 presents some simulation results on the proposed algorithms, and the paper is concluded in Section 5.

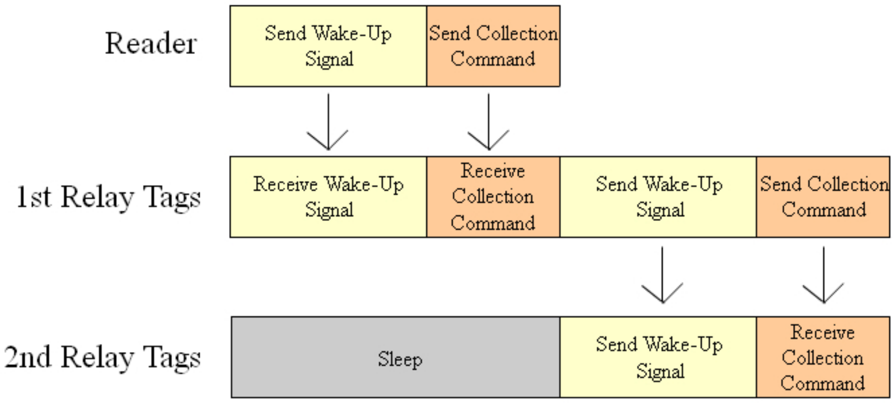
2 Related Works

A lot of standardization work has been done for passive RFID tags [2, 4]. However, the majority of protocols for active RFID tags are proprietary. Existing active RFID protocols [7]. can be divided into three types: Free2move based active RFID protocols [6, 1], IEEE 802.15.4 standard (Zigbee MAClayer), and ISO-18000 based protocols [5, 2, 3].

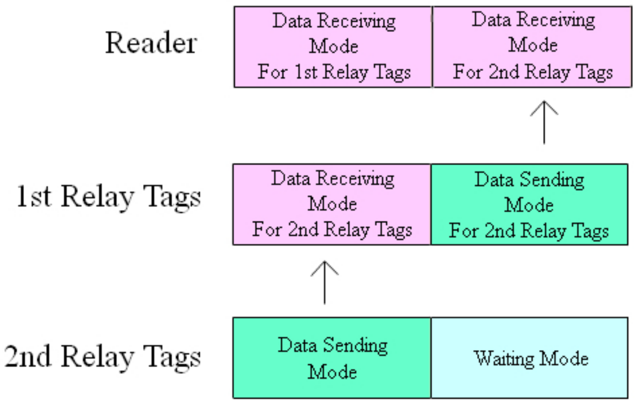
Free2move is a protocol based on Frequency Hopping Spread Spectrum and Time Division Multiple Access. It works either in the synchronized mode (reader talks first (RTF) mode) or in the non-synchronized mode (tag talks first (TTF) mode). In the RTF mode, the reader broadcasts beacon signals periodically to create a slotted scheme. Between two beacon signals, the reader keeps listening to detect any response from the tags. The reader listens to 2 frequency channels and can receive two frames at the same time. For a tag, when sending a frame, it randomly chooses a frequency channel from the specified two channels. As for working in the TTF mode, a tag wakes up and sends frame to the reader randomly if needed. Then the tag keeps listening and waits for an acknowledge message from the reader. If there is no acknowledge message, the tag will change to sleep mode and wake up later to send the same frame again. In the TTF mode, the tag will not detect the beacon signal before it transmits a frame.

802.15.4 protocol is a contention based slotted protocol. In this protocol, a reader continuously sends beacon signals. A tag periodically wakes up and tries to detect a beacon signal. If it detects a beacon signal, it may then send information frame to the reader; otherwise, the tag will change to sleep mode immediately. Later, it will wake up and repeat the same process.

For ISO-18000 based protocols, the reader always talks first. All tags will keep sleeping until a reader wakes them up for data collection. When a round of data collection has been accomplished, all tags will go sleep again. That means the tags will always keep mute unless the reader let them talk. Although there are some multi-hop relay algorithms has been proposed for active algorithms [8, 5], they are designed based on ISO-18000, which focus on helping the reader do data collection and does not support TTF working mode. For example, figure 1 shows the 2-hop frame structure in [8]. We can find that the multiple 2-hop relay tags are not waked up by the reader directly, but by the multiple 1st relay tags. Besides, the query (collection command) is also received from other tags, not from the reader.



(a) Forward link



(b) Backward link

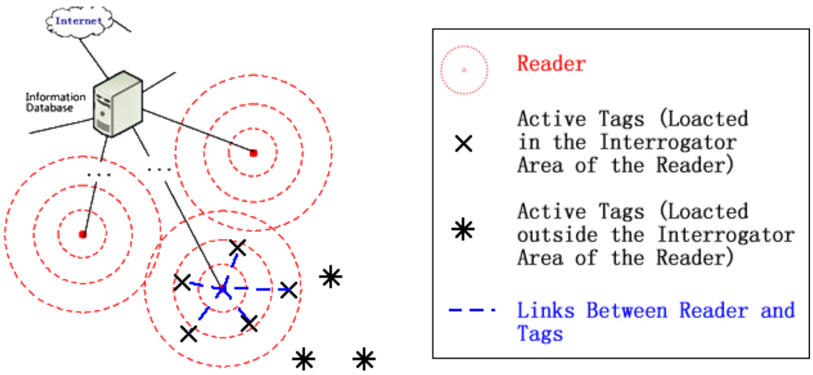
Figure 1: 2-hop frame structure in [8].

Although ISO-18000 based protocols do not support TTF work mode directly, it can achieve similar goal by periodically information collected: the reader wakes up all the active tags periodically and collect the information if any. However, the energy cost is very high to wake up all of the tags and ask all of them to join into routing. Besides, the delay cost by waiting for the periodic query and wake-up process is also very high.

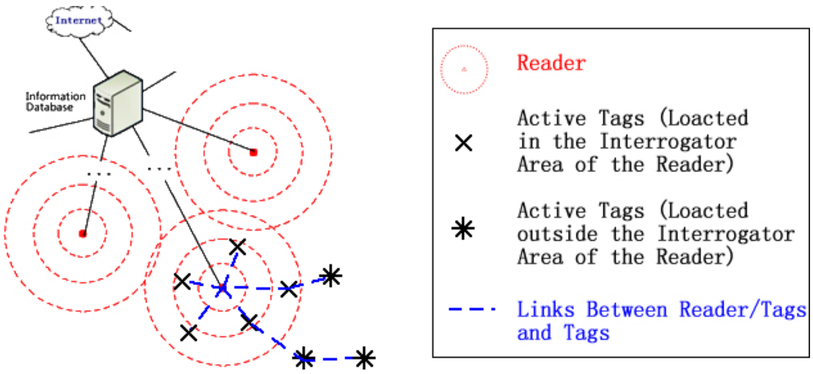
In the following session, we propose two multi-hop relay algorithms used in TTF mode. They are work for the first two types of protocols (Free2move and 802.15.4) respectively. Compared to the ISO-18000 based protocols with periodically information collection, they are much more energy-efficient and real-time.

3 Multi-hop Relay Algorithms in TTF Mode

The main purpose of using multi-hop relay algorithms for RFID network is to extend the working area (or eliminate the dead-zone) when the hardware is specified (see figure 2). As a result, the loss of the network is reduced. Some multi-hop relay algorithms for RTF mode have been proposed. However, no such algorithms have been proposed for TTF mode. It means that although a reader may collect information from an active tag which is located outside the interrogator area of the reader, the same active tag still cannot send frames to the reader actively.



(a) An RFID network without any multi-hop relay mechanism.



(b) The same RFID network with some multi-hop relay mechanism used.

Figure 2: multi-hop relay algorithms can help to extend the working area and reduce the number of connection-lost tags.

In the following part of this session, we describe two proposed multi-hop relay algorithms, which work for Free2move protocol and 802.15.4 standard respectively.

3.1 Multi-hop relay algorithm for Free2move protocol

In the TTF mode of the original Free2move protocol, although the reader sends beacon signals periodically, the tags do not detect them before transmit frames. On the contrary, a tag may wake up and send frame to the reader randomly if needed. After a tag sends a frame, it waits for an acknowledge message from the reader. If there is no reader available in the sense area of the tag, it will not receive any acknowledge message. Traditionally, the tag will change to sleep and wake up later to try again in this case. The behaviors of the tag are shown in figure 3.

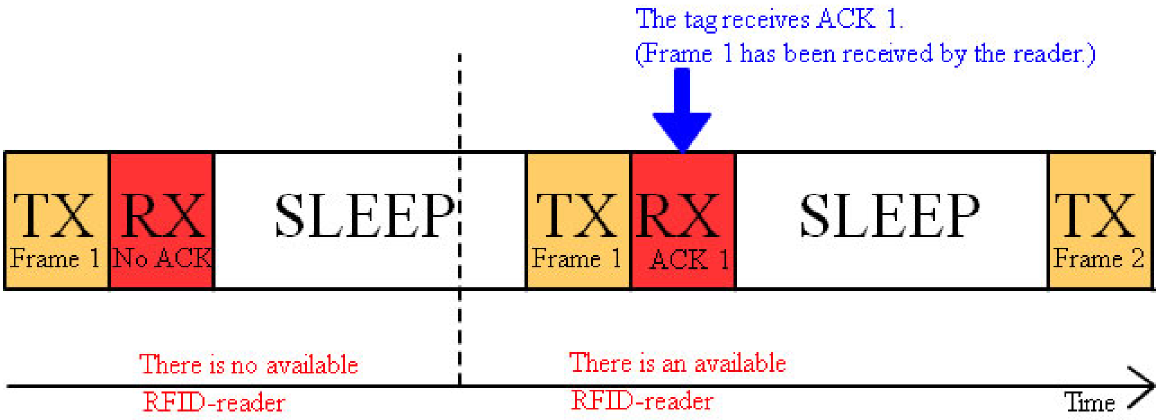


Figure 3: behaviors of an active tag in TTF mode of Free2move protocol without any multi-hop relay mechanism.

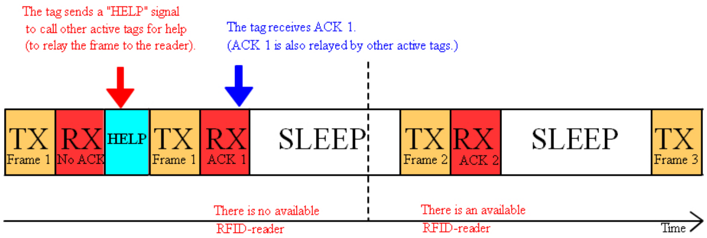
To realize the multi-hop relay mechanism, two kinds of signals may be broadcasted by the source tag (or rebroadcasted by relay tags), as shown in table 1.

Control Signals	Description
Help Signal	Let all nearby waking active tags keep awake for a short time (to prevent them from sleeping), and ask them to help relay frames.
Stop Signal	Terminate this round of multi-hop relay process.

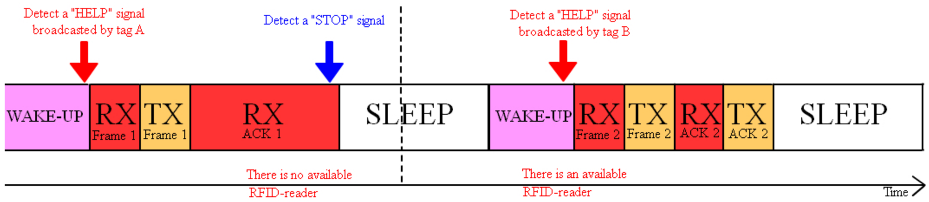
Table 1: two kinds of control signals in TTF mode for Free2move.

In our proposed algorithm, if a waking active tag receives a Help signal, then in a short time period t (16 times the amount of time for one frame transmission), when it receives a information frame (no matter from the source tag or from another active relay tag) for the first time, it will try to relay the frame. As for the Stop signal, it is broadcasted by the source tag after it has received an acknowledgement message successfully. When nearby active tags receive Stop signal, they will terminates its relay process and rebroadcast the Stop signal. After that, they turn back to their original state (e.g. change into sleep mode).

With two-hop relay mechanism used (see figure 4a), when the source tag does not receive an acknowledge message, it will call other active tags for help. All the active tags which have detected the help signal, will change into receive mode (Rx) if they have no frames to transmit by themselves. Besides, to avoid these relay tags turn to sleep mode suddenly and give up the multi-hop relay process, all of them will keep awake for a short time (32 times the amount of time for one frame transmission) or until they detect a Stop signal. After receiving the information frame from the source tag, the relay tag chooses a frequency channel from the specified two channels, and performs a carrier sense. If the channel is free, it starts to transmit the frame. Otherwise, it sets up a back-off timer with the range of time slot [0,7], and then tries to relay the frame. After relaying the frame, the relay tag changes to receive mode again and waits for an acknowledge message. If this relay tag receives one, it will also relay the acknowledgement message. The behaviors of the relay tag are shown in figure 4b.



(a) Behaviors of the source active tag.



(b) Behaviors of the relay active tags.

Figure 4: behaviors of active tags in TTF mode of Free2move protocol with a multi-hop relay mechanism.

The behaviors of the relay tags mentioned in the preceding part are for two-hop relay process. To evolve a multi-hop relay mechanism, more operations should be added. In order to control the flooding, the maximum number of hops needs to be determined. Here we use TTL to count the number of hops passed by. Besides, the Help signal and Stop signal may also be relayed by relay tags (due to the value of TTL). The pseudo-code for the algorithm at relay tags is shown below:

Algorithm 1 Whenever the relay tag detects a Stop signal, it will terminate the process, relay the Stop signal and change back to the original state of itself.

1: BEGIN
2: Receive Help Signal
3: Check TTL
4: If ($TTL > 1$)
5: Broadcast Help Signal and TTL
6: Receive Information Frame
7: Do a Carrier Sense
8: If ($ChannelIsFree$)
9: Relay the Frame
10: Else
11: Makes a Back-off for a Random Time t
12: Wait for Time t
13: Repeat to Do a Carrier Sense and Relay the Frame
14: End If
15: Else
16: Goto Line 24
17: End if
18: Wait for ACK
19: If (Receive ACK)
20: Do a Carrier Sense and Relay ACK
21: Else if (Time is out)
22: Goto Line 24
23: End if
24: END

3.2 Multi-hop relay algorithm for 802.15.4 protocol

In 802.15.4 protocol, a reader keeps sending beacon signals every 16 time lots, and the tags wake up periodically. Whenever a tag has some information for the reader, it will try to find a reader by detecting the beacon signal. If it detects one, it then sends an information frame and waits for the acknowledge message; otherwise, the tag will change to sleep mode and repeat the same process when it wakes up for the next time. The behaviors of the active tag in the TTF mode are shown in figure 5.

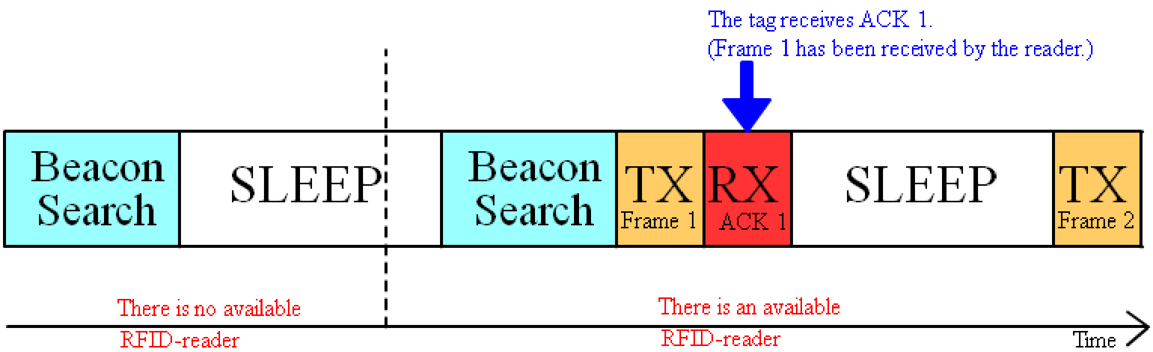


Figure 5: behaviors of an active tag in 802.15.4 without multi-hop relay mechanism.

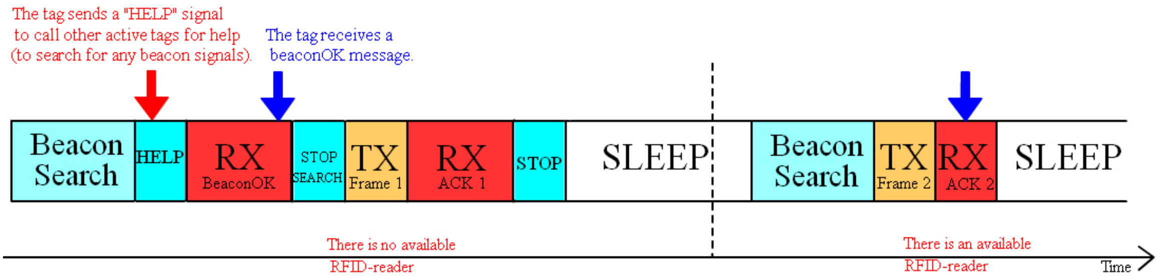
To realize a multi-hop relay mechanism in 802.15.4, three kinds of signals may be broadcasted by the source tag (or rebroadcasted by relay tags), as shown in table 2:

Control Signals	Description
Help Signal	Let all nearby waking active tags keep awake for a short time(to prevent them from sleeping), and ask them to help do beacon search.
Stop Search Signal	Terminate this round of beacon search.
Stop Signal	Terminate this round of multi-hop relay process.

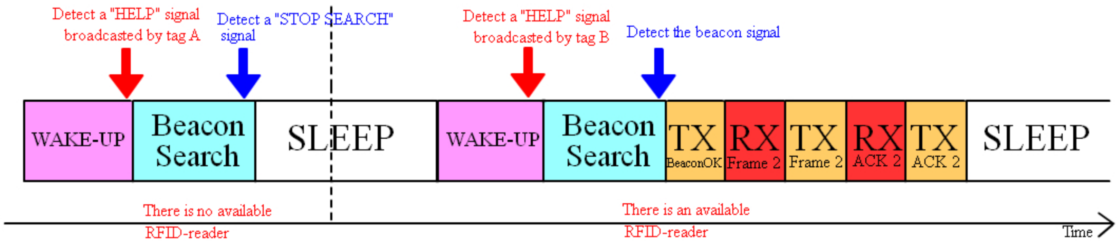
Table 2: three kinds of control signals for 802.5.4.

If a waking active tag receives a Help signal, then it will do beacon search for at most 16 time slots (which equals to the cycle of beacon signals). At the same time, it keeps listening to others' beaconOK message. If it detects a beacon signal from the reader or receives a beaconOK message from other relay tags, it will set up a back-off timer and wait to broadcast a beaconOK message. Whenever the source tag receives the beaconOK message, it will broadcast a Stop Search signal. As for the stop signal, it is similar to that of the Free2move. It is broadcasted by the source tag to terminate the whole round of multi-hop relay process.

The whole process can be divided into two sessions: beacon search session and frame relay session. In figure 6a, it shows the behaviors of the source tag after we introduce the two-hop relay mechanism to 802.15.4 protocol. The source tag sends a Help signal when it does not detect any beacon signal by itself. Differently from that of Free2move, the relay tags received Help signal will not prepare to relay the information frame immediately. These tags will try to find out a beacon signal. In two-hop relay process, when a beacon signal is detected by some relay tag, this relay tag will send a BeaconOK message to the source tag directly. Then the source tag will broadcast a Stop Search signal. After that, it begins to transmit the information frame, and only the tag which has detected the beacon signal will relay the frame. The behaviors of the relay tag are shown in figure 6b.



(a) Behaviors of the source active tag.



(b) Behaviors of the relay active tags.

Figure 6: behaviors of active tags in TTF mode of 802.15.4 protocol with a multi-hop relay mechanism.

The behaviors of the relay tags shown in the preceding part are for two-hop relay process. To evolve a multi-hop relay mechanism, the TTL is also needed, but it is used in beacon search session, not in frame relay session. In beacon search session, the Help signal and Stop Search signal are also relayed by relay tags (due to the value of TTL). In this session, if a relay tag detects the beacon signal, or receives a beaconOK message from aother relay tag, it will mark itself for further frame relay process. When the source tag receives a beaconOK message, it will broadcast a Stop Search signal. All the tags which receive this signal, but have not marked themselves (i.e. neither has detected the beacon signal nor has relayed a beaconOK message), will not join into the frame relay session at all. In order to reduce the number of redundant frames in the network and to save energy of the active tags, these tags will terminate the relay process and change back to their original states. Later, these tags which have been marked, will help relay the information frame and the Stop signal. The pseudo-code for the algorithm at relay tags is shown below (algorithm 2).

To compare the performance before and after using the multi-hop relay mechanism, we do some simulations. The simulation results are shown in the next session.

4 Simulation Results

In the following, simulation results on the original protocols (Free2move and 802.15.4), and the protocols using proposed multi-hop relay algorithms in TTF mode will be reported. To compare the loss performance of with and without multi-hop relay mechanisms, simulations on the same networks have been run. After that, we compare the energy and delay performances of using proposed algorithms with those of using ISO-18000 based protocols (to achieve similar goal by periodically information collected with multi-hop relay mechanism in RTF mode).

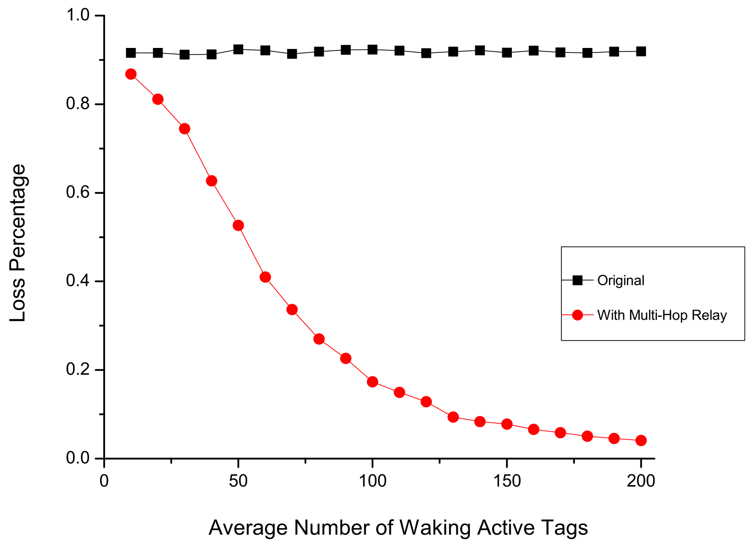
The following simulations are run in a square area. The reader is put at the center of the area, while active tags are randomly located. The size of active tags vary from 1000 to 20000, while the average waking time percentage for all active tags is 1%. That means on the average, the number of waking tags is from 10 to 200. The whole simulation period is divided into time slots such that in each time slot, at most one signal or one frame can be generated/relayed by the reader or the tags. As signals from active tags can only be received within 4m - 5m normally, the response range of active tags is set to 4m in our simulation. We assume that all active tags have the same processing

Algorithm 2 When the tag is executing code from line 2 to line 12 (beacon search session), whenever it detects a Stop Search signal, it will terminate the process and change back to the original state of itself. Whenever the tag detects a Stop signal, it will terminate the process and change back to the original state of itself.

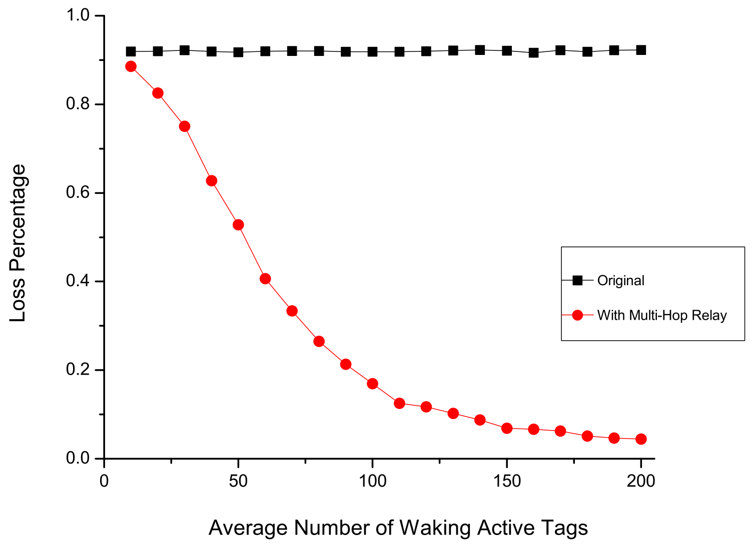
```
1: BEGIN
2: Receive and Check TTL
3: Broadcast Help Signal
4: Broadcast TTL
5: If (TTL > 1)
6: If (detect a beacon signal OR receive a beaconOK message)
7: Remark Itself As "True Relay Tag"
8: Do a Carrier Sense
9: Send the beaconOK message
10: End If
11: End If
12: If (Receive a Stop Search signal)
13: If (Itself has been remarked as"True Relay Tag" )
14: Receive Information Frame
15: Make a back-off for a random time t
16: Wait for Time t
17: Do a Carrier Sense
18: Relay the Frame
19: Else
20: Goto Line 28
21: End if
22: End if
23: Wait for ACK
24: If (Receive ACK)
25: Do a Carrier Sense
26: Relay ACK
27: End if
28: END
```

capacity and the same buffer size, which are 1 frame per time slot and 2 buffer respectively. In each time slot, each waking tags may generate a frame with probability 0.001. As for the TTL, it is set to 10 for both of the proposed algorithms and ISO-18000. The maximum number of back-off timer is set to 7 for both of the proposed algorithms. For 802.15.4, the cycle of beacon signals is 16. If the source tag cannot receive any acknowledge message (which may due to collision, or no path between itself and the reader is built successfully), this round of data transmission is failed. In this case, the source tag will broadcast Stop signal and then broadcast the Help signal to retransmit the same frame. The frame retransmission will be operated for at most 2 times.

In the first simulation, the simulation area is 25mX25, and we compare the loss performance of protocols (with and without multi-hop relay mechanisms), vs. the number of waking active tags. From figure 7, we find that for both Free2move and 802.15.4 protocols, when using multi-hop relay mechanisms, the loss percentages are much smaller than those of the original ones. It is easily understood that some frames sent by the active tags (which are not located in the interrogation area of the reader) may also be received by the reader through multi-hop connections. When the number of active tags is small, to build up multi-hop connections for tags may be difficult. In some extreme cases, for all of the waking active tags, there is no other active tag in their sense areas. So when the number of waking active tags is small (especially less than 10), the loss percentage is still very high compared to with more waking active tags in the network.



(a) Free2move



(b) 802.15.4

Figure 7: loss performance for the original protocols (Free2move and 802.15.4), and the same protocols but using proposed multi-hop relay algorithms.

We also compare the loss percentages of the two proposed algorithms with that of ISO-18000 based relay algorithm. From figure 8, we can find that with the same number of average waking active tags, the loss percentages for these three algorithms are quite similar.

With the total number of active tags unchanged, the size of the area also make a difference in the results. In the next simulation, we varies the size of the simulation area and calculate the loss percentages for the proposed algorithms. As the two proposed algorithms gives similar simulation results on loss performance, we only show the result of proposed algorithm for Free2move here. From figure 9, we can find that when the average number of active tags is the same, ones with smaller

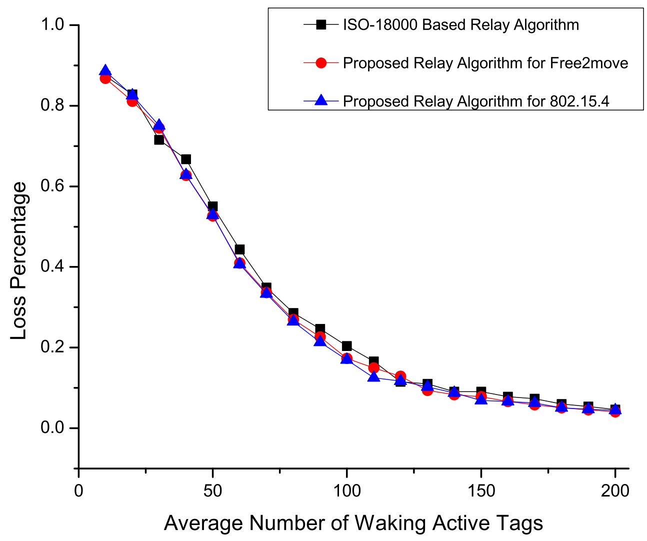


Figure 8: loss performance for the two proposed algorithms and ISO-18000 based relay algorithm.

sizes of the area give better performance than those with larger ones. It can be understood that when the size of the area increased, the density of active tags is decreased. For a specified tag, on average, there are less tags locate in its sense area. As a result, it is more difficult to build-up a multi-hop connection between the source tag and the reader.

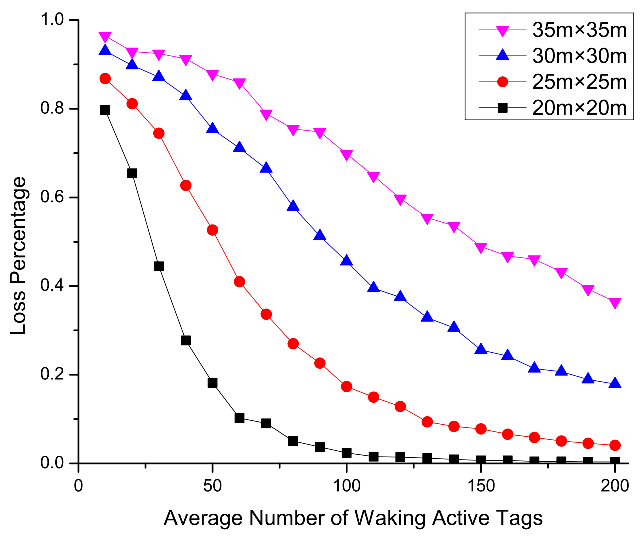


Figure 9: the loss performance of proposed algorithm for Free2move when the size of the area changes.

Next, we present the energy performance. In this simulation, each time when a signal/frame is transmitted or received by a tag, the energy of this tag is consumed by 1 unit. If the source tag cannot receive any acknowledge message (which may due to collision, or no path between itself and the reader is built successfully), the energy consumed by it will still be counted, while the source tag will broadcast Stop signal and then broadcast the Help signal to retransmit the same frame. Each frame may be retransmitted for at most 2 times. At the end of the simulation, we calculate the average energy consumption for all frames which have been delivered to the reader successfully.

Figure 10 presents the energy performance for ISO-18000 based multi-hop relay algorithm with periodically information collected, and the energy performance for proposed relay algorithms for Free2move and 802.15.4. From this figure, we can find that the energy performances of proposed multi-hop relay algorithms are much better than that of ISO-18000 based one. It is because that when the reader collects information in ISO-18000 based multi-hop relay algorithm, all of the active tags in the network will be forced to wake up and prepared to help others to relay frames. A lot of energy is costed for this process. Furthermore, when the average number of waking active tags is small, e.g. less than 90, the energy performance for multi-hop relay algorithm for 802.15.4 is better than that for Free2move. The main reason is that when the number of waking tags is small, the loss percentage is high. For multi-hop relay algorithm used in 802.15.4, there are 2 sessions: the beacon search session and the frame relay session. Only the tags which have detected the beacon signal or relay the beaconOK message will join the second session. As the probability for not detecting the beacon signal is high, the probability for the network not operating the second session is also high. In this case, the energy is saved that all the tags do not need to receive or relay the information frame (see figure 11 for comparison in which the loss probability equals to 1). On the contrary, when the average number of waking tags is larger than 110, the energy performance for multi-hop relay algorithm for Free2move is better than that for 802.15.4. It is because that when the loss percentage is very low, in the first session of 802.15.4, to receive and relay beaconOK message costs more energy. Meanwhile, as the beacon signals are periodically broadcasted, when waiting for the beacon signals, more active tags may be forced to do beacon search (however, some multi-hop connections already can be built-up without the new more ones). So the energy cost is increased. As a result, with average number of waking tags is larger than 100, the average energy cost of proposed algorithm for 802.15.4 is larger than that of the one for Free2move.

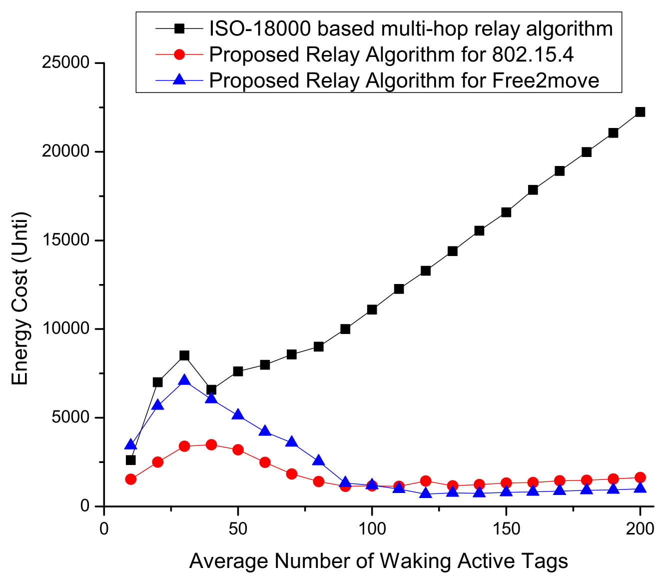


Figure 10: energy performance for the ISO-18000 based multi-hop relay algorithm and the proposed multihop relay algorithms.

We also evaluate the energy cost in the case that there is no available RFID reader in the simulation area(see figure 11). As ISO-18000 cannot work without a reader, we only consider the two proposed algorithms in this simulation. From this figure, we find that when there is no available reader, the energy cost of proposed algorithm for 802.15.4 is much higher than that of the proposed algorithm for Free2move. With the average number of waking tags increased, the energy cost is also increased.

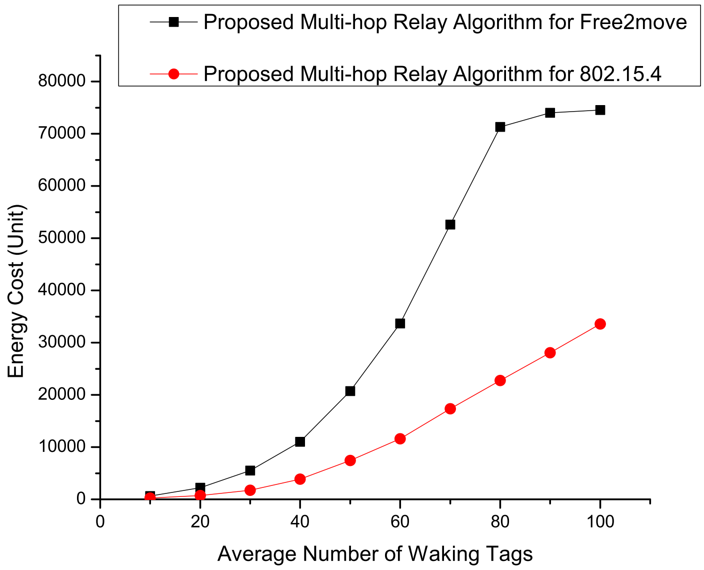


Figure 11: energy performance two proposed multihop relay algorithms when there is no available reader (which means all frames are lost).

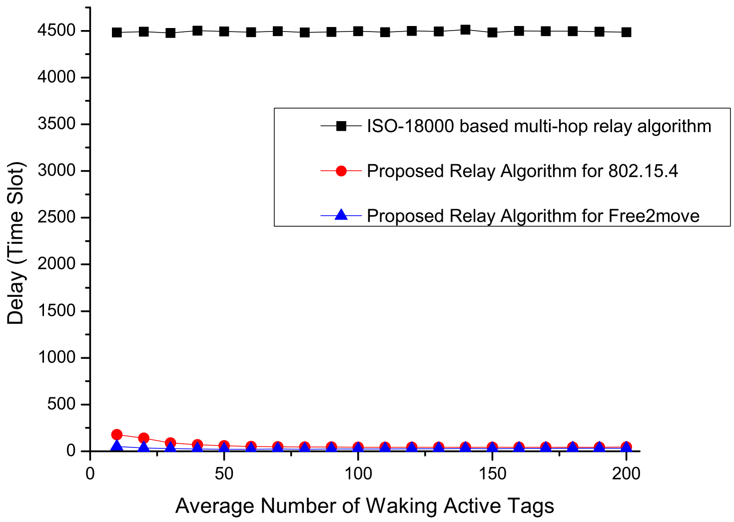


Figure 12: delay performance for proposed multi-hop relay algorithms and for ISO-18000 based multi-hop relay algorithm.

Finally, we compare the delay performances for proposed algorithms with ISO-18000 based multi-hop relay algorithm. We focus on the frames which have been received by the reader successfully and calculate the average delay of them. Each time slot is set to 6ms in this simulation. From figure

12, we can find that the delay for ISO-18000 based multi-hop relay algorithm is much longer than the other two. It is because that the time cost for waking up each layer (i.e. each hop) of active tags is 2.5 - 2.7 seconds. When $TTL = 10$, the delay is about ten times amount of the time costed for each hop. We also find that the delay of proposed algorithm for Free2move is shorter than the other one. It is because that in 802.15.4, before transmitting the information frame, the source tag needs to find out a beacon signal first. To wait for the beacon signal cost many time. Besides, after the source tag ensure that there is a connection between itself and the reader, time is cost to transmit the information frame to the reader hop-by-bop. So the delay for this algorithm is longer than that of the proposed algorithm for Free2move.

5 Conclusion

In this paper, we have proposed two multi-hop relay algorithms for RFID networks in Tag-Talks-First mode. They are designed based on Free2move and 802.15.4 respectively. Simulation results show that when using the proposed algorithms, the loss performance is much better than that of the original protocols. Besides, the energy performance and delay performance is better than those of using ISO-18000 based multi-hop relay algorithm (i.e. without using multi-hop relay algorithms in Tag-Talks-First mode, but using periodical data collection in Reader-Talks-First mode instead).

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