2009－DPS－138 (23)
2009－CSEC－ 44 (23)
2009／3／5

TDMA Slot Assignment for Higher Availability and Shorter Transmission Delay

Shusuke Tsumura and Hiroaki Higaki
Department of Computers and Systems Engineering
Tokyo Denki University
E-mail: {tsumura, hig}@higlab.net

TDMA is one of the efficient methods for achieving contention- and collision-free mobile ad-hoc networks. In conventional proactive methods, a slot is assigned to each mobile computer independently whether it is included in a wireless multihop transmission route or not. This paper proposes a reactive slot assignment method in which slots are assigned to only intermediate mobile computers in wireless multihop transmission routes. Especially in an environment with high density distribution of mobile computers and low frequency of communication requests, successful slot assignment ratio gets higher due to weaker restrictions on slot assignments. In addition, since slots are assigned after detection of wireless transmission routes, it is possible for each intermediate mobile computer to select a slot with shorter waiting time to forward data messages, i.e. reduction of end-to-end transmission delay is expected. This paper designs a novel slot assignment protocol with consideration for the shorter waiting time. Results of simulation experiments show that the proposed protocol achieves avaragely 51.0% shorter transmission delay than the conventional protocol for proactive slot assignment method.

TDMAを用いたモバイルアドホックネットワークにおける通信遅延短縮手法

東京電機大学大学院 理工学研究科 情報システム工学専攻
津村 周典　桧垣 博章
E-mail: {tsumura, hig}@higlab.net

モバイルアドホックネットワークにおいて衝突と競合を回避するために TDMA を導入する手法が考えられる。これまでに提案されているプロアクティブ型手法では、無線マルチホップ配送経路に含まれているか否かに関わらず、すべての移動コンピュータにスロットを割り当てていた。本論文では、経路に含まれる中継移動コンピュータにのみスロットを割り当てるリアクティブ型手法を提案する。特に、移動コンピュータの分布密度が高く通信要求頻度が低い場合には、スロット割り当て制約が緩和されるため割り当て成功率が改善される。また、経路を定めた後にスロットを割り当てるため、マルチホップ配送における中継ノードでの転送待ち時間を短縮するようにスロットを選択することが可能であり、配送遅延の短縮が見込まれる。この転送待ち時間短縮を考慮したスロット割り当てプロトコルを設計し、シミュレーション実験評価した結果平均 51.0%の配送遅延が短縮された。

1 Introduction

Recently, research on wireless ad-hoc networks consisting of multiple mobile computers with wireless communication devices has been getting active. It is expected for wireless ad-hoc networks to be applied to temporary networks for disaster rescue, ITS (Intelligent Transport Systems), conventions, conferences and networks which is difficult to be configured as wired networks due to physical and/or economical reasons. This is because a wireless ad-hoc network consists only of wireless mobile computers without base stations which require high configuration and maintenance cost. Here, communication between mobile computers is realized by a wireless signal transmission which is based on broadcasting. Hence, multiple mobile computers share the communication medium. It is critical for wireless communication to avoid contentions and collisions for message transmission with shorter transmission delay, lower loss ratio and higher throughput. Adoption of TDMA (Time Division Multiple Access) is one of the efficient solutions for solving this problem. In a wireless ad-hoc network, contentions and collisions occur not only between neighbor mobile computers but also between 2-hop neighbor mobile computers due to the hidden terminal problem. In conventional methods, available slots for a wireless multihop transmission of messages are determined based only on network topology regardless whether each 2-hop neighbor mobile computer engages to other wireless multihop transmissions or not. Hence, applied restrictions are too tight and successful slot assignment ratio gets lower especially in an ad-hoc network with low frequency of message transmission requests and with high density of mobile computers. This paper proposes a novel slot assignment method for TDMA with consideration of not only network topology but also existence of requests for message transmissions for achieving high successful slot assignment ratio and shorter transmission delay in a wireless ad-hoc network.

2 Related Works

Usually, there is limited battery capacity in a mobile computer in an ad-hoc network. In addition, reduction of contentions and collisions is required to achieve shorter transmission delay and higher throughput. Hence, not all messages are transmitted directly from a source mobile computer to a destination one. Each mobile computer transmits messages to its neighbor mobile computers with limited transmission power. Hence, messages are transmitted from a source mobile computer to a destination one along a wireless multihop transmission route with help of intermediate mobile computers which forward the messages. Here, a wireless LAN protocol such as IEEE802.11 [1], Bluetooth [2] and ZigBee [3] is applied for 1-hop transmission of messages between neighbor mobile computers. These protocols are based on CSMA/CA and RTS/CTS for avoidance and reduction of contentions and collisions. However, especially in a wireless ad-hoc network with high density of mobile computers, since frequency of contentions gets high, longer transmission delay is required and throughput gets lower. In order to solve this problem, routing and message transmission protocols for avoidance of contentions and collisions within a wireless multihop transmission route with transmission power control have been proposed. In [6], a route modification protocol for avoidance of contentions and collisions among multiple multihop transmission routes has been proposed .

On the other hand, in [4] and [7], it has been proposed to realize wireless multihop transmissions without contentions and collisions by applying TDMA. As shown in Figure 1, a time slot for transmission of messages is assigned to a mobile computer. In case that a same time slot is assigned to two neighbor mobile computers M_i and M_j and another mobile computer M_k is included in wireless signal transmission ranges of both M_i and M_j, messages are lost due to collision when both M_i and M_j transmit messages in the assigned slot and at least one of them is destined to M_k. This problem also occurs when M_i and M_j are 2-hop neighbor mobile computers since these mobile computers are hidden terminals by M_k. Thus, by assigning a slot to a mobile computer different from slots already assigned to 1-hop and 2-hop neighbor mobile computers, contention- and collision-free wireless ad-hoc networks are realized.

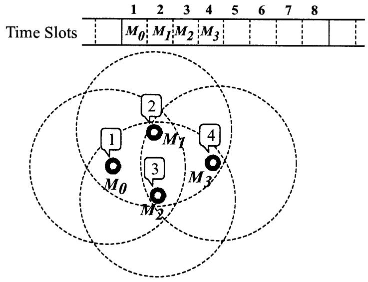

Fig. 1: TDMA Slot Assignments.

In the conventional TDMA slot assignment methods, an assignment of a slot to a mobile computer is restrected by slot assignments in all 1-hop and 2-hop neighbor mobile computers. If a same slot is assigned to the mobile computer M as a 1-hop or a 2-hop neighbor mobile computer M', collision of wireless signals occurs if these mobile computers transmits simultaneously. Thus, one of the slots which has not yet been assigned to all 1-hop and 2-hop neighbor mobile computers of M is selected and assigned to M. USAP [7] and ASAP [4] are proactive TDMA slot assignment methods in which assigned slot is determined only by topology of a wireless ad-hoc network. Here, a slot is assigned to each mobile computer regardless whether the mobile computer is included in a wireless multihop transmission route or not. Each time a mobile computer is added to the wireless ad-hoc network or moves and its neighbor mobile computers change, a slot is required to be (re-)assigned. Since it is possible for a mobile computer to transmit messages to one of its neighbor mobile computers with the assigned slot, a slot which has not yet assigned to all 1-hop and 2-hop neighbor mobile computers should be assigned.

In this method, an assigned slot is different from those assigned to all 1-hop and 2-hop neighbor mobile computers and no contentions and collisions occur with direct 1-hop neighbor mobile computers and with 2-hop neighbor ones with the hidden terminal relation. However, more than $|N_1(M_i)| + |N_2(M_i)| + 1$ slots are required for a slot assignment to a mobile computer M_i where $N_1(M_i)$ and $N_2(M_i)$ are sets of 1-hop and 2-hop neighbor mobile computers of M_i, respectively. Hence, for a wireless mobile ad-hoc network, more than $\max_i\{|N_1(M_i)|+|N_2(M_i)|+1\}$ slots are required. Therefore, successful slot assignment ratio gets lower in a wireless mobile ad-hoc network with high density mobile computer distribution since the number of 1-hop and 2-hop neighbor mobile computers is large. In ASAP, number of slots is dynamically changed according to number of 1-hop and 2-hop neighbor mobile computers. However, for large number of slots in a mobile computer, a period of a slot should be longer and throughput of wireless multihop transmission should be lower. In addition, since the slots are also assigned to neighbor mobile computers which are not engaged in any wireless multihop transmission, efficiency of the network also gets lower.

3 Proposal

3.1 Reactive Slot Assignment

In order to solve the problem mentioned in the previous section, this paper proposes a novel method for reactive (on-demand) TDMA slot assignments in which a slot is assigned only to a mobile computer included in a wireless multihop transmission route. In addition, though all slots assigned to 1-hop and 2-hop neighbor mobile computers are not assigned due to potential possibility of contentions and collisions in conventional reactive slot assignment methods, only slots which have already been assigned and whose assignment surely causes contentions and collisions are avoided to be assigned in the proposed method. Hence, there are more candidate slots for assignment to a mobile computer and higher successful assignment ratio is expected. In conventional proactive assignment methods, a slot is assigned to each mobile computer to transmit messages to any neighbor mobile computers as shown in Figure 2. On the other hand, in reactive assignment methods, a slot is assigned to only mobile computers included in an active wireless multihop transmission route and the slot is used for transmission of messages along the route as shown in Figure 3.

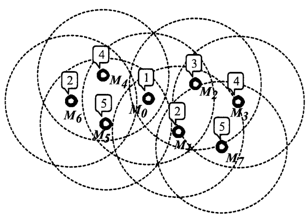

Fig. 2: Proactive Slot Assignment.

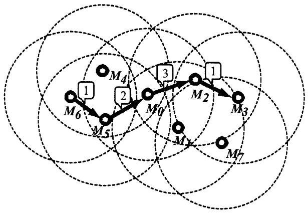

Fig. 3: Reactive Slot Assignment.

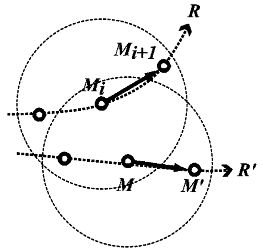

Fig. 4: Wireless Links with Assignments of Same Slot.

3.2 Restrictions on Slot Assignment

This section shows restrictions on slot assignments in a mobile computer M_i included in a wireless multihop transmission route $R = ||M_0 \ldots M_n\rangle\rangle$ from a source mobile computer $M_s(= M_0)$ to a destination one $M_d(= M_n)$ where wireless signal transmissions from M_i to M_{i+1} do not cause contentions and collisions with those in other wireless multihop transmissions. Here, let $N_1(M)$ and $N_2(M)$ be sets of 1-hop and 2-hop neighbor mobile computers of a mobile computer M.

If one of the following conditions is satisfied, it is impossible for a slot s to be assigned to M_i for transmission of messages through a wireless communication link $|M_iM_{i+1}\rangle$:

- If M_i transmits messages in s, collisions occur with messages being transmitted to M_i.
- If M_i transmits messages in s, collisions occur with messages being transmitted to neighbor mobile computers of M_i except for M_{i+1}.
- If M_i transmits messages in s, collisions occur with messages being transmitted to M_{i+1} from a neighbor mobile computer of M_{i+1}.

In [5], restrictions on slot assignments to wireless communication links has been discussed and two restrictions have been induced. In order for slot assignment to a wireless communication link $|M_iM_{i+1}\rangle$, it is not required for all assigned slots which have been assigned to 1-hop and 2-hop neighbor mobile computers of M_i to be restricted. Even if a slot s has already been assigned to a wireless communication link $|MM'\rangle$ from a 1-hop neighbor mobile computer $M \in N_2(M_i)$ of M_i to its neighbor mobile computer $M' \in N_1(M)$, it is possible for s to be assigned to $|M_iM_{i+1}\rangle$ if M is not a neighbor of M_{i+1} and M' is not a neighbor of M_i, i.e. $M \notin N_1(M_{i+1})$ and $M' \notin N_1(M_i)$ as shown in Figure 4. Therefore, the restrictions for a slot s to be assigned to a wireless communication link $|M_iM_{i+1}\rangle$ are as follows:

[Restrictions on Slot Assignments]
A slot s satisfying the following conditions is allowed to be assigned to a wireless communication link $|M_iM_{i+1}\rangle$:

- s has not yet been assigned to a wireless communication link $|M'M\rangle$ where $M \in N_1(M_i)$ and $M' \in N_1(M)$.
- s has not yet been assigned to a wireless communication link $|MM'\rangle$ where $M \in N_1(M_{i+1})$ and $M' \in N_1(M)$.

□

3.3 Slot Selection for Shorter Transmission Delay

In wireless multihop transmission, after receipt of a data message from a previous hop mobile computer, an intermediate mobile computer should keep the message until it forwards the data message in its assigned slot. Let s_i be a slot assigned to a wireless communication link $|M_iM_{i+1}\rangle$, i.e. an intermediate mobile computer M_i in a wireless multihop transmission route $R = |M_0 \ldots M_n\rangle$ transmits data messages in s_i. M_i receives a data message in s_{i-1} and forwards s_i. Hence, the data message is kept in M_i for $\{s_i - s_{i-1} \bmod N_s\}$ where N_s is a number of slots in a frame. Therefore, for multihop transmission of a data message, $\sum_{0<i<n}\{s_i - s_{i-1} \bmod N_s\}$ transmission delay is required.

In conventional proactive slot assignment protocol, a slot is assigned to each mobile computer regardless whether the mobile computer is included in a wireless multihop transmission route or not as in the left figure in Figure 5. Hence, when a wireless multihop transmission route is detected, an expected transmission delay is automatically determined as in the right figure in Figure 5.

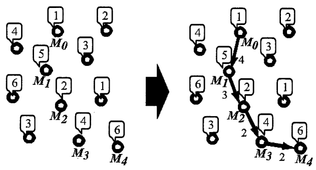

Fig. 5: Transmission Delay in Proactive Slot Assignment ($N_s = 6$).

On the other hand, in reactive slot assignment protocol, a slot is assigned after the wireless transmission route is detected. Hence, if s_{i-1} has been assigned before s_i, M_i selects s_i which satisfies the restrictions in the previous subsection and where $\{s_i - s_{i-1} \bmod N_s\}$ is the minimum for shorter transmission delay.

4 Slot Assignment Protocol

This section shows a TDMA slot assignment protocol based on the method proposed in the previous section. Here, a wireless multihop transmission route $R = ||M_0 \ldots M_n\rangle\rangle$ from a source mobile computer M_0 to a destination one M_n has been detected by an ad-hoc routing protocol. The following sets of slots are stored in each mobile computer M_i in R:

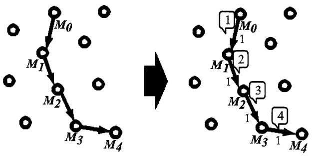

Fig. 6: Transmission Delay in Reactive Slot Assignment ($N_s = 6$).

- SS_i: a set of slots assigned to a wireless communication link $|MM'\rangle$ where M is M_i or a neighbor mobile computer of M_i and M' is a neighbor mobile computer of M, i.e. $|MM'\rangle$ is included in an active wireless multihop transmission route.
- RS_i: a set of slots assigned to a wireless communication link $|M'M\rangle$ where M is M_i or a neighbor mobile computer of M_i and M' is a neighbor mobile computer of M, i.e. $|M'M\rangle$ is included in an active wireless multihop transmission route.

According to the slot assignment restrictions in subsection 3.2, one of slots s where $s \notin RS_{i-1} \cup SS_i$ should be assigned to a wireless communication link $|M_{i-1}M_i\rangle$. In addition for shorter transmission delay, $\{s_i - s_{i-1} \bmod N_s\}$ should be smaller according to the discussion in subsection 3.3. In the following slot assignment protocol, a slot is assigned to each wireless communication link in R in the forward direction, i.e. from M_0 to M_n. Hence, when s_i is selected, s_{i-1} has already been selected.

[Slot Assignment Protocol]
(Source Mobile Computer M_0)
1) A source mobile computer M_0 transmits a slot request message *Sreq* with RS_0 and $\perp$ (dummy slot) to its next hop mobile computer M_1.
2) On receipt of a slot reply message *Srep* with a slot s assigned to a wireless communication link $|M_0M_1\rangle$ from M_1, M_0 adds s to SS_0 and broadcasts a sending slot append request message SS^+*req* with s.

(Intermediate Mobile Computer M_i)
1) On receipt of an *Sreq* message with RS_{i-1} and s_p from M_{i-1}, an intermediate mobile computer M_i selects a slot s where $s \notin RS_{i-1} \cup SS_i$ and $s - s_p \bmod N_s$ is the minimum.
2) M_i adds s to RS_i, transmits an *Srep* message with s to M_{i-1} and broadcasts a receiving slot append request message RS^+*req* with s.
3) M_i transmits an *Sreq* message with RS_i and s to its next hop mobile computer M_{i+1}.
4) On receipt of an *Srep* message with a slot s assigned to a wireless communication link $|M_iM_{i+1}\rangle$ from M_{i+1}, M_i adds s to SS_i and broadcasts a SS^+*req* message with s.

(Destination Mobile Computer M_n)
1) On receipt of an *Sreq* message with RS_{n-1} and s_p from M_{n-1}, a destination mobile computer M_n selects a slot s where $s \notin RS_{n-1} \cup SS_n$ and $s - s_p \bmod N_s$ is the minimum.
2) M_n adds s to RS_n, transmits an *Srep* message with s to M_{n-1} and broadcasts an RS^+*req* message with s.

(Neighbor Mobile Computer M_j)
1) On receipt of an RS^+*req* message with a slot s assigned to a wireless communication link $|M_{i-1}M_i\rangle$ from M_i, M_j adds s to RS_j.
2) On receipt of an SS^+*req* message with a slot s assigned to a wireless communication link $|M_iM_{i+1}\rangle$ from M_i, M_j adds s to SS_j.

□

[Slot Release Protocol]
(Source Mobile Computer M_0)
1) On detection of release of R, a source mobile computer M_0 removes s assigned to a wireless communication link $|M_0M_1\rangle$ from SS_0 and broadcasts a sending slot release request message SS^-*req* with s.

(Intermediate Mobile Computer M_i)
1) On detection of release of R, an intermediate mobile computer M_i removes s assigned to a wireless communication link $|M_{i-1}M_i\rangle$ from RS_i and broadcasts a receiving slot release request message RS^-*req* with s.
2) M_i removes s assigned to a wireless communication link $|M_iM_{i+1}\rangle$ from SS_i and broadcasts an SS^-*req* message with s.

(Destination Mobile Computer M_n)
1) On detection of release of R, a destination mobile computer M_n removes s assigned to a wireless communication link $|M_{n-1}M_n\rangle$ from RS_n and broadcasts an RS^-*req* message with s.

(Neighbor Mobile Computer M_j)
1) On receipt of an RS^-*req* message with a slot s assigned to a wireless communication link $|M_{i-1}M_i\rangle$ from M_i, M_j removes s from RS_j.
2) On receipt of an SS^-*req* message with a slot s assigned to a wireless communication link $|M_iM_{i+1}\rangle$ from M_i, M_j removes s from SS_j.

□

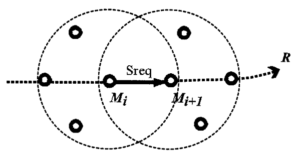

Fig. 7: Unicast Transmission of *Srep*.

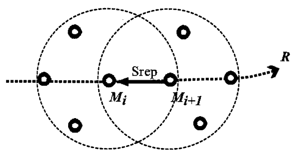

Fig. 8: Broadcast Transmission of RS^+*req*.

5 Evaluation

This section shows results of simulation experiments for evaluation of our proposed method.

The first evaluation shows that a slot assignment in a mobile computer in our proposed method has weaker

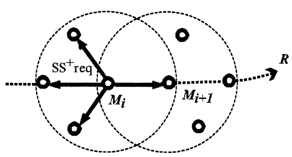

Fig. 9: Unicast Transmission of $Sreq$.

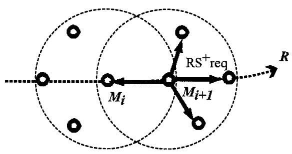

Fig. 10: Broadcast Transmission of $SS^{+}req$.

restrictions on slot assignments in other mobile computers than in the conventional method. Here, 300–500 mobile computers are randomly distributed in a 1200m×1200m field according to unique distribution randomness, a source and a destination mobile computers are also selected randomly and a wireless multihop transmission route is detected by using AODV. Numbers of wireless communication links for which slot assignment is restricted by the slot assignments to wireless communication links along the detected wireless multihop transmission route are evaluated. Wireless transmission range of each mobile computer is assumed to be 100m. Figure 13 shows an evaluation result. Here, the ratio of numbers of restricted mobile computers in our proposed method against numbers in the conventional method is evaluated. The minimum, maximum and average ratios are 0.508, 0.813 and 0.761, respectively. Hence, there are averagely 33.9% weaker restrictions on slot assignments in our proposed method.

The second evaluation shows successful slot assignments ratio in our proposed reactive method and in the conventional proactive method with various numbers of mobile computers and numbers of active wireless multihop transmission routes. Here, 200–800 mobile computers are randomly distributed in a 1000m×1000m field according to unique distribution randomness. In the proactive method, a slot is assigned to each mobile computers. In our reactive method, a source and a destination mobile computers are selected randomly, a wireless multihop transmission route is detected by using AODV and a slot is assigned by our proposed protocol. Wireless transmission range of each mobile computer is 100m and there are 16 TDMA slots for data message transmissions.

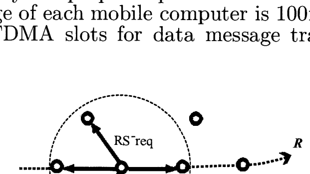

Fig. 11: Broadcast Transmission of $RS^{-}req$.

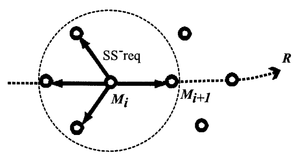

Fig. 12: Broadcast Transmission of $SS^{-}req$.

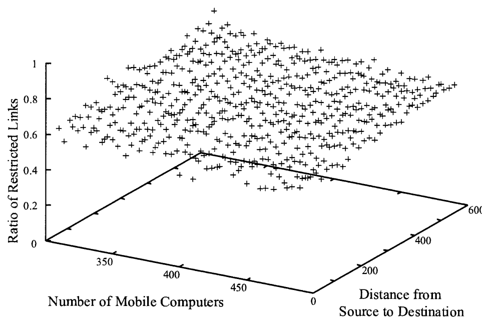

Fig. 13: Ratio of Restricted Wireless Links.

In addition, since performance of the proposed reactive method depends on number of available slots, i.e. slots which have not yet been assigned, the number of other active wireless multihop transmission routes is assumed to be 1–30, which represents different frequency of communication requests in a wireless mobile ad-hoc network.

Figure 14 shows results of simulation experiments. In the proactive slot assignment method, since a slot is assigned to each mobile computers independently of communication requests, successful slot assignment ratio is independent of the number of wireless transmission route. Since a slot which has already been assigned to one of 1-hop and 2-hop neighbor mobile computers is not prohibited to be assigned, in higher density environments, successful slot assignment ratio is low due to large number of 1-hop and 2-hop neighbor mobile computers. On the other hand, in the reactive method, since a slot is assigned to each mobile computer only included in a wireless multihop transmission route, successful slot assignment ratio depends on number of other active wireless multihop transmission route. The larger the number of routes is, the lower the successful slot assignment ratio is. However, the ratio is almost independent of the number of mobile computers in a wireless mobile ad-hoc networks since no slots are assigned to mobile computers which are not engaged in wireless multihop transmissions [1]. Therefore, almost all the cases, the proposed reactive slot assignment method achieves higher successful slot assignment ratio than the conventional proactive method.

Finally, end-to-end transmission delay is evaluated. Since slots are assigned to all mobile computers before detection of wireless multihop transmission routes in

[1]Successful slot assignment ratio is evaluated low in cases with small number of mobile computers and large number of wireless transmission route since an additional wireless multihop transmission route is failed to be detected due to low connectivity.

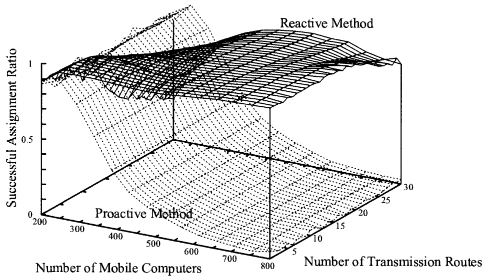

Fig. 14: Successful Slot Assignment Ratio.

conventional proactive slot assignment methods and slots are assigned to only the intermediate mobile computers after detection of wireless multihop transmission routes in proposed reactive slot assignment method, reduction of end-to-end transmission delay is expected. Here, 300–1000 mobile computers with 100m wireless transmission range are distributed in a 1000m × 1000m field according to unique distribution randomness. Communication requests arrive according to Poisson Process with 100msec and 200msec average intervals and communication time is 1sec (constant). AODV routing protocol is applied for detection of wireless multihop transmission routes and numbers of slots are constantly 8 and initially 4 in our proposed reactive slot assignment method and ASAP which is a proactive slot assignment method with variable number of slots, respectively. Figures 15 and 16 show the simulation results with 100msec and 200msec average request intervals, respectively. Longer end-to-end transmission delay is required in an environment with higher density of mobile computers in ASAP since a slot different from those assigned to all 1-hop and 2-hop neighbor mobile computers should be assigned to each mobile computer and the number of slots is increased. On the other hand in our method, end-to-end transmission delay is averagely 54.5% and 47.5% shorter than ASAP and is independent of density of mobile computers since slots are assigned to only intermediate mobile computers in wireless transmission routes whose numbers of hops are less effective to density of mobile computers in AODV.

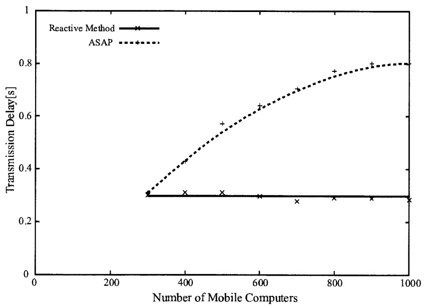

Fig. 15: Transmission Delay with 100msec Request Interval.

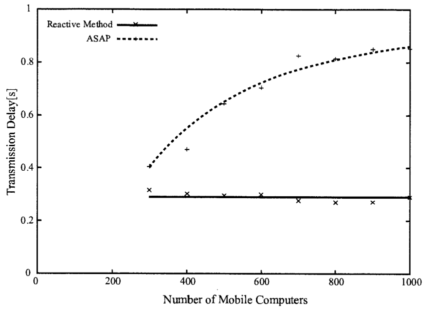

Fig. 16: Transmission Delay with 200msec Request Interval.

6 Conclusion

This paper has proposed a reactive TDMA slot assignment method for avoidance of contentions and collisions in wireless multihop transmission in wireless mobile ad-hoc networks and designed slot assignment and release protocols. In the proposed method, a slot assignment to a wireless communication link along a wireless multihop transmission route is restricted only by part of slot assignments in 1-hop and 2-hop neighbor mobile computers. Hence, it achieves higher successful slot assignment ratio than the conventional proactive slot assignment method. The results of simulation experiments show that the reactive method achieves averagely 55.4% higher assignment ratio. In addition, the proposed method achieves averagely 51.0% shorter end-to-end transmission delay since slots are assigned to intermediate mobile computers in a wireless multihop transmission route after it is detected by an ad-hoc routing protocol.

References

[1] "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," Standard IEEE 802.11 (1997).

[2] "Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs)," Standard IEEE 802.15.1 (2002).

[3] "Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs)," Standard IEEE 802.15.4 (2003).

[4] Kanzaki, A., Uemukai, T., Hara, T. and Nishio, S., "TDMA Slot Assignment Protocols Considering the Number of Nodes in Ad Hoc Networks," Transactions of Information Processing Society of Japan, Vol. 45, No. 3, pp. 824–837 (2004).

[5] Tsumura, S. and Higaki, H., "TDMA Slot Assignment Protocol for Active Multihop Transmission Route in Mobile Ad-Hoc Networks," IPSJ Technical Report, Vol. 2007, No. 91, pp. 73–78 (2007).

[6] Umeshima, S. and Higaki, H., "Power Control Based Ad Hoc Routing Protocol," IEICE Technical Report, Vol. 103, No. 443, pp. 57–60 (2003).

[7] Young, C.D., "USAP: A Unifying Dynamic Distributed Multichannel TDMA Slot Assignment Protocol," Proceedings of the IEEE Military Communications Conference, pp. 235–239 (1996).