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Wireless Sporadic Communication Protocol for Supporting Cluster-to-Base Station Communication

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Recently, mobile computers have become able to communicate with each other by using a wireless LAN protocol, e.g. IEEE802.11 and HIPERLAN, for supporting various internet services. In case that a mobile computer changes a location with high speed, less messages are exchanged between the mobile computer and the Internet. This paper proposes a novel routing protocol CB-WSCP for a mobile clustered networks in which mobile computers with almost the same velocity and communication with each other by multi-hop transmission form a cluster. Here, communication between a cluster and a base station is available iff at least one mobile computer in the cluster is within a transmission range of the base station. Hence, it is required to support sporadic communication. For achieving wider bandwidth even though the cluster moves with a high speed, a proposed protocol achieves switching of gateways and updating of routing tables.

移動コンピュータ群-基地局間の間欠的通信プロトコルとその性能評価

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近年、IEEE802.11 や HIPERLAN といった無線 LAN プロトコルを用いてモバイルコンピュータとインターネット上のサービスとの通信が行なわれるようになってきている。モバイルコンピュータが高速で移動する場合、モバイルコンピュータとインターネットとの間で交換される情報量は少なくなる。本論文では、複数のモバイルコンピュータがほぼ同じ速度で移動し、互いにマルチホップ通信可能なモバイルコンピュータ群を対象としたルーティングプロトコル CB-WSCP を提案する。本プロトコルでは、モバイルコンピュータ群と基地局との通信は基地局の通信範囲内に存在する群内のモバイルコンピュータを介して行なわれる。群内のモバイルコンピュータと基地局との通信は、少なくても１つのモバイルコンピュータが基地局の通信セル内に存在するときにのみ可能となることから、本プロトコルは間欠的通信をサポートする必要がある。本論文では、高速に移動するモバイルコンピュータ群により広帯域な通信を提供するためのゲートウェイの切替えプロトコル、および、それにともなうルーティングテーブルの更新について述べる。また、提案プロトコルの性能を DSDV と比較し、その有効性を明らかにする。

1 Background and Objective

Recently, mobile computers not only handheld, laptop and palmtop personal computers (PCs), personal data assistants (PDAs) and personal information appliances (PIAs) but also computers in auotomobiles for intelligent transport systems (ITS) and computers for controlling autonomous mobile robots have become widely available. Since users of mobile computers request to access server computers for achieving internet services at any time and at any place, mobile computers are required to communicate with other computers through the Internet. In order for exchanging information between mobile computers, infrared wireless communication is widely used. Furthermore, for implementing a LAN (Local Area Network) to which mobile computers are connected by using wireless communication devices, wireless LAN protocols such as series of IEEE802.11 [2] and HIPERLAN [1] have been developed and standardized. According to network architectures, wireless LANs are classified into three categories; *infrastructured networks*, *multihop-access networks* and *ad-hoc networks*. In an infrastructured network, base stations are used as a gateway between a mobile computer and a wired network. A mobile computer m communicates with another computer c only when m is in a transmission range of a base station b and vice versa. A message exchanged between m and c is transmitted through b. A series of IEEE802.11 protocols are widely available for supporting an infrastructured network with the help of DHCP (Dynamic Host Configuration Protocol) [5] and MobileIP [8].

In a multihop-access network, if a mobile computer m is in a transmission range of a base station b, a message between m and another computer c is directly exchanged between m and b and transmitted through wired and/or wireless networks between b and c as in an infrastructured network. In addition, even if m is out of a transmission range of any base station, m exchanges a message with b if multi-hop access between m and b is available, i.e. there is a sequence of mobile computers $\langle m_0(=m), \ldots, m_n(=b)\rangle$ where m_{i+1} is in a transmission range of m_i $(i = 0, \ldots, n-1)$ and m_{i-1} is in a transmission range of m_i $(i = 1, \ldots, n)$. Here, a routing protocol for transmitting a message between m and b is required. That is, a mobile computer is required to serve a role of a router. Since not only m but also intermediate mobile computers change locations, a routing protocol has to achieve a currently available route.

In an ad-hoc network, there is no base station and only mobile computers are connected to the network. Due to a bounded transmission range of a mobile computer m, m does not always exchange a message directly with another mobile computer m'. Thus, all (or most of) mobile computers are engaged in routing of a message and multi-hop transmission is required to exchange a message between m and m'. Here, a routing protocol for supporting mobility of computers is required.

Furthermore, wireless LANs are classified into following two categories based on characteristics of mobility of computers, i.e. characteristics of change in network topology; *autonomous mobile computer networks* and *clustered mobile computer networks*. In an autonomous mobile computer network, each mobile computer changes a location autonomously as shown in Figure 1. Computer networks with multiple mobile computers in conventions and conferences, computer networks for disaster rescue and sensor networks are instances of autonomous mobile computer networks. Until now, many kinds of routing protocols, e.g. DSR [7], DSDV [9], AODV [10] and LBSR [11], for supporting such networks have been proposed.

In a clustered mobile computer network, the network is composed of multiple *clusters* of mobile computers as shown in Figure 2. Each cluster consists of multiple mobile computers that move with almost the same velocity. That is, for velocities $\vec{v_i}$ and $\vec{v_j}$ of mobile computers m_i and m_j in a cluster of mobile computers, respectively, $|\vec{v_i} - \vec{v_j}| < \delta$. Mobile computer networks for supporting a cooperating system with multiple autonomous robots, intelligent transport systems (ITS) with multiple computers devised on automobiles and a mobile computer network in a battlefield are instances of clustered mobile computer networks.

This paper discusses a routing protocol for supporting communication in a wireless LAN with base stations. Though a base station is critical for transmission of a message through a wired network, high cost and overhead for construction and maintenance of base stations are required to achieve a network in which a mobile computer always communicates with a base station directly. Hence, communication between a mobile computer and a base station is *sporadic*. If a mobile computer m changes a location with a low speed $|\vec{v}| < v$, sufficient number of messages might be exchanged between m and a base station b. However, if m changes a location with a high speed $|\vec{v}| \geq v$, especially when messages carry multimedia data, required number of messages might not be exchanged between m and b while m is in a transmission range of b and vice versa.

Hence, this paper proposes a routing protocol CB-WSCP (Cluster to Base Station Wireless Sporadic Communication Protocol) for supporting sporadic communication and achieving transmission of more messages between a base station and a cluster of mobile computers changing locations with high speed.

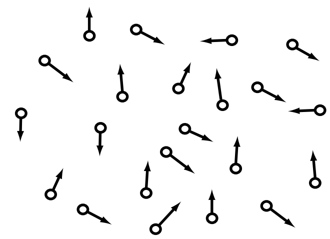

Figure 1: Autonomous mobile computer network.

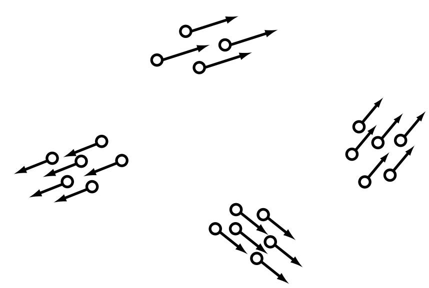

Figure 2: Clustered mobile computer network.

2 Related Works

For routing a message by multi-hop transmission in a mobile network, i.e. in a multihop-access network and an ad-hoc network, many routing protocols have been designed and developed. These routing protocols are classified into the following two categories; *topology management routing protocols* and *on-demand routing protocols*. By using the former, a routing table in each mobile computer is kept up to date to reflect any changes of a network topology. DSDV [9] is the most popular topology management protocol. On the other hand, by using the latter, a transmission route of a message from a mobile computer m_s to another one m_r is searched just before m_s transmits the message destined to m_r. DSR [7], AODV [10] and LBSR [11] are on-demand routing protocols. Though these protocols are designed to support mobility and limited battery capacity of mobile computers, most of them is based on an assumption that a location of a mobile computer does not change so rapidly, i.e. a network topology is so stable that a detected route is available while the mobile computer communicates by using the route. Hence, it is difficult to simply apply these protocols to a set of mobile computers changing locations rapidly.

In order to reduce route discovery and route maintenance overhead, cluster-based routing protocols have been proposed. A cluster is a set of mobile computers. In CBRP (Cluster Based Routing Protocol) [3, 6] and Spine Routing [4, 12], one of the mobile computers in each cluster serves a role of a *cluster head.* A message *mes* transmitted by a mobile computer m_s in a cluster C_s is forwarded to a cluster head h_s of C_s. *mes* is routed to a cluster head h_d of C_d in which a destination mobile computer m_d is included. Only cluster heads and gateways of other clusters are engaged in a message transmission from h_s to h_d. Here, a mobile computer that is neither a cluster head nor a gateway changes its location without effect to message routing. That is, low overhead route maintenance is achieved. In these protocols, a cluster is determined based on locations of mobile computers independently of mobility of mobile computers. In addition, these protocols are assumed to be applied to autonomous mobile computer networks where mobile computers move with low speed. Hence, these protocols are not designed to support sporadic communication where clusters of mobile computers locate sparsely and move with high speed.

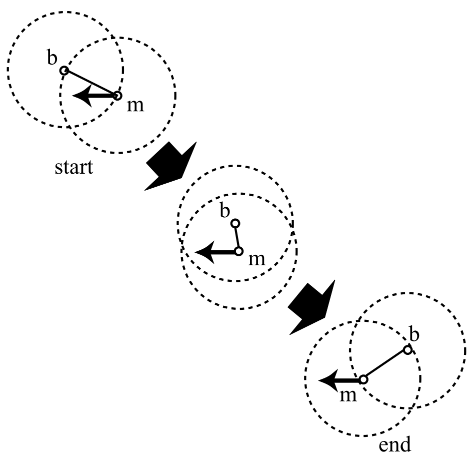

Figure 3: Mobile computer based communication.

3 CB-WSCP Protocol

As shown in Figure 3, a mobile computer m and a base station b communicates with each other directly only if m is in a transmission range of b and vice versa.

On the other hand, as shown in Figure 4, suppose that a mobile computer m is included in a cluster C of mobile computers. Let a mobile computer g in C be a gateway for communication between C and a base station b, i.e. g is in a transmission range of b. If there exists such a mobile computer as g, m and b exchange messages with each other even though m is out of a transmission range of b. A message *mes* from m to a computer out of C is transmitted to g by using multi-

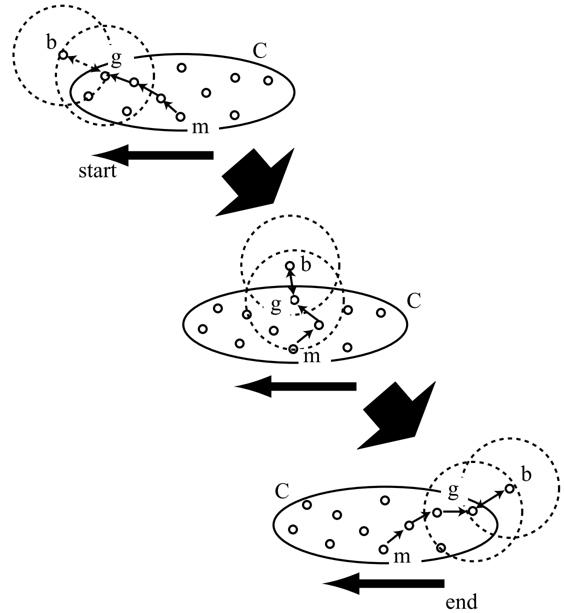

Figure 4: Cluster based communication.

hop transmission and directly forwarded to b. That is, even if m is out of a transmission range of b, if $\exists g \in C$ where g is in a transmission range of b, *mes* is exchanged by multi-hop transmission in C and direct transmission between g and b. This method is effective to achieve wider bandwidth for message transmission especially when clusters move with high speed.

In order to support sporadic communication between a base station b and a cluster C of mobile computers, this paper proposes CB-WSCP (Cluster to Base Station Wireless Sporadic Communication Protocol) for dynamically switching a gateway mobile computer in C for b due to change of a location of C. Here, a cluster is defined as follows:

[**Multi-hop Transmission Reachability**] Mobile computers m and m' in a cluster C are *multi-hop transmission reachable* $m \approx m'$ iff there is a sequence $\langle m_0(= m), \ldots, m_n(= m')\rangle$ $(m_i \in C)$ of mobile computers where m_{i+1} is in a transmission range of m_i $(i = 0, \ldots, n-1)$ and m_{i-1} is in a transmission range of m_i $(i = 1, \ldots, n)$. □

[**Cluster**] Let $\vec{v_i}$ and $\vec{v_j}$ be velocities of mobile computers m_i and m_j, respectively. A set C of mobile computers is a *cluster* iff for $\forall m_i, \forall m_j \in C$, $|\vec{v_i} - \vec{v_j}| < \delta$ and $m_i \approx m_j$. □

If multiple mobile computers in a cluster C independently and autonomously communicate with a base station b, throughput between C and b is reduced due to occurrences of contentions and collisions in a wireless LAN protocol such as IEEE802.11 based on CSMA/CA. Especially if mobile computers in C move with high speed, it is critical to avoid occurrences of contentions and collisions since the time duration in which messages are exchanged between C and b is short. Hence, CB-WSCP is designed to hold that at most one mobile computer in C communicates with b.

[Gateway] If a mobile computer g is a *gateway* in a cluster C for a base station b, g exchanges a message directly with b. A message exchanged between a mobile computer $m(\neq g)$ and a computer out of C is transmitted through g and b. At most one mobile computer in C serves role of a gateway for b. □

[Assumptions] In CB-WSCP, the following are assumed:

- Velocity $\vec{v_i}$ of a mobile computer m_i does not change rapidly, i.e. $|d\vec{v_i}/dt| < \delta$.
  A set of mobile computers in a cluster C does not change. That is, no mobile computer join to and leave from C.
- While a cluster C and a base station b communicate with each other, at least one mobile computer in C is in a transmission range of b. Suppose that a mobile computer $m \in C$ is in a transmission range of b. Before m gets out of the transmission range of b, another mobile computer $m' \in C$ gets into the transmission range.
- A cluster C exchanges messages with at most one base station, simultaneously. If a mobile computer $m \in C$ is in a transmission range of a base station b, no mobile computer in C is in a transmission range of another base station b'. □

CB-WSCP consists of two protocols: a gateway switching protocol and a table updating protocol. By the former protocol, role of a gateway is delegated from a current gateway to a new gateway. A base station achieves an address of the new gateway and updates its routing table as a next hop for a message destined to a mobile computer in C is the new gateway. Due to change of a gateway, routing tables of mobile computers might become obsolete. Hence, routes between the Internet, i.e. a base station, and mobile computers in C are kept up-to-date by using the latter protocol.

3.1 Beginning of Communication

In order to detect that a cluster C and a base station b becomes to be able to communicate with each other, i.e. a mobile computer in C gets into a transmission range of b, b broadcasts a *gw_req* message within a transmission range of b repeatedly with a time interval τ_b. In order for at most one mobile computer surely to become a gateway even though multiple mobile computers in C gets into a transmission range of b successively, each *gw_req* is assigned a sequence number *gw_req.seq* $\in N$ by b. In addition, for updating a routing table in each mobile computer in C and b, a *gw_chg* message with an address of the gateway is transmitted by using a flooding protocol. For avoiding inconsistent routing tables in mobile computers in C, *gw_req.seq* is copied to *gw_chg.seq*.

[Gateway Switching Protocol]

1. On receipt of a *gw_req* message transmitted from a base station b, a mobile computer g_1 finds that g_1 gets into a transmission range of b and that a cluster C including g_1 becomes to be able to communicate with other computers out of C through b. g_1 broadcasts a *gw_chg*(g_1) message to all mobile computers in C and b within a transmission range of g_1. Here, *gw_chg*(g_1)*.seq* := *gw_req.seq*.
2. On receipt of *gw_chg*(g_1), a base station b updates a routing table as that a message destined to a mobile computer in C is forwarded to g_1. □

[Table Updating Protocol]

1. After g_1 broadcasts a *gw_chg*(g_1) message as described in step 1 of the gateway switching protocol, g_1 updates a routing table as that a message destined to a computer out of C is forwarded to b and stores *gw_req.seq* into $tbl.seq_{g_1}$.
2. On receipt of a *gw_chg*(g_1) message from a mobile computer m_{nbr}, a mobile computer m_i compares *gw_chg*(g_1)*.seq* with $tbl.seq_{m_i}$.
   - If *gw_chg*(g_1)*.seq* $> tbl.seq_{m_i}$, *gw_chg*(g_1)*.seq* is stored into $tbl.seq_{m_i}$.
     - If a next hop for a message destined to a computer out of C is not m_{nbr}, m_i updates a routing table as that such a message is forwarded to m_{nbr} and broadcasts the *gw_chg*(g_1) message to all mobile computers within a transmission range of m_i.
     - Otherwise, m_i dose not broadcast the message.
   - Otherwise, i.e. *gw_chg*(g_1)*.seq* $\leq tbl.seq_{m_i}$, m_i does not broadcast the message. □

According to this protocol, g_1 becomes a gateway in C for b and a message from a mobile computer in C to a computer out of C is forwarded to g_1 by using multi-hop transmission in C. In addition, the *gw_chg* message is transmitted to not all mobile computers in C to reduce communication overhead.

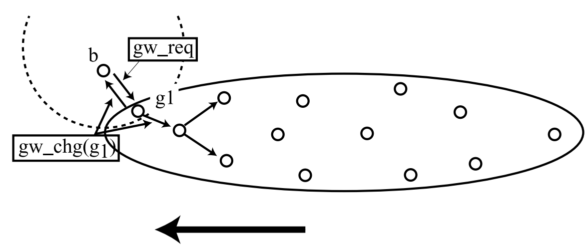

Figure 5: Beginning of communication.

3.2 Switching of Gateway

Due to movement of a mobile computer, a gateway g_i in a cluster C for a base station b moves out of a transmission range of b. Hence, before g_i gets out, a role of a gateway should be switched to another mobile computer g_{i+1} in C. That is, as changing a location of C, a gateway for b is switched from g_i to g_{i+1}. It is possible that a gateway is switched from g_i to g_{i+1} at any moment after g_{i+1} gets into a transmission range of b before g_i gets out of the transmission range of b. In the following protocol, the switching is invoked when

g_{i+1} gets into the transmission range of b.

[Gateway Switching Protocol]

1. On receipt of a *gw_req* message transmitted from a base station b, a mobile computer g_{i+1} finds that g_{i+1} gets into a transmission range of b and broadcasts a $gw\_chg(g_{i+1})$ message to all mobile computers in C and b within a transmission range of g_{i+1}. Here, $gw\_chg(g_{i+1}).seq := gw\_req.seq$. $gw\_chg(g_{i+1}).up := b$ and $gw\_chg(g_{i+1}).down$ contains all mobile computers stored in a routing table of $gw\_chg(g_{i+1})$ as destination mobile computers.
2. On receipt of a $gw\_chg(g_{i+1})$ message from a mobile computer m_{nbr}.
   - If $gw\_chg(g_{i+1}).seq > tbl\_seq_{g_i}$, g_i stores $gw\_chg(g_{i+1}).seq$ into $tbl.seq_{g_i}$ and broadcasts the $gw\_chg(g_{i+1})$ message to all mobile computers within a transmission range of g_i according to step 1 of the table updating protocol since a next hop for a default route is $b \neq m_{nbr}$. Until a transmission buffer in g_i for messages destined to a computer out of C becomes empty or g_i gets out of a transmission range of b, g_i forwards the messages to b. Then, g_i updates a routing table as that a message destined to a computer out of C is forwarded to m_{nbr} according to the steps of the table updating protocol and transmits a $gw\_switch(g_1, g_{i+1})$ message to g_{i+1} by using multi-hop transmission in C. Here, $gw\_switch(g_1, g_{i+1}).seq := gw\_chg(g_{i+1}).seq$.
   - Otherwise, g_i follows step 1 of the table updating protocol.
3. On receipt of a $gw\_switch(g_1, g_{i+1})$ message,
   - if $gw\_switch(g_1, g_{i+1}).seq > tbl.seq_{g_{i+1}}$, g_{i+1} stores $gw\_switch(g_1, g_{i+1}).seq$ into $tbl.seq_{g_{i+1}}$ and updates a routing table as that a next hop for a default route is b.
   - otherwise, g_{i+1} does not update a routing table. □

[Table Updating Protocol]

1. On receipt of a $gw\_chg(g_{i+1})$ message from a mobile computer m_{nbr}, a mobile computer m_i compares $gw\_chg(g_{i+1}).seq$ with $tbl.seq_{m_i}$.
   - If $gw\_chg(g_{i+1}).seq > tbl.seq_{m_i}$, m_i stores $gw\_chg(g_{i+1}).seq$ into $tbl.seq_{m_i}$.
     – If a next hop for a default route, i.e. the next hop for a computer out of C, is not m_{nbr}, m_i updates a routing table as that m_{nbr} is a next hop for a default route and broadcasts the $gw\_chg(g_{i+1})$ to all mobile computers within a transmission range of m_i after the following modification: $gw\_chg(g_{i+1}).up := m_{nbr}$ and $gw\_chg(g_{i+1}).down$ contains all mobile computers stored in a routing table of m_{nbr} as destination mobile computers.
     – Otherwise, m_i dose not broadcast the message.
   - If $gw\_chg(g_{i+1}).seq = tbl.seq_{m_i}$.
     – If $gw\_chg(g_{i+1}).up = m_i$, m_i adds entries for all mobile computers in $gw\_chg(g_{i+1}).down$ whose next hop is m_{nbr} to a routing table of m_i. m_i sends a *tbl_update* message to a next hop for default route. Here, $tbl\_update.seq := gw\_chg(g_{i+1}).seq$, $tbl\_update.add := gw\_chg(g_{i+1}).down$ and $tbl\_update.del := \phi$.
     – If $gw\_chg(g_{i+1}).up \neq m_i$ and m_i is included in a routing table of m_i as a destination mobile computer, m_i deletes all entries whose next hop is m_{nbr} from a routing table of m_i. m_i sends a *tbl_update* message to a next hop for a default route. Here, $tbl\_update.seq := gw\_chg(g_{i+1}).seq$, $tbl\_update.add := \phi$ and $tbl\_update.del$ contains all mobile computers which deleted from a routing table of m_i in this step.
     – Otherwise, m_i does not send any *tbl_update*.
   - Otherwise, i.e. $gw\_chg(g_{i+1}).seq < tbl.seq_{m_i}$, m_i does not broadcast the message.
2. On receipt of a *tbl_update* message from a mobile computer m_{nbr}.
   - If $tbl\_update.seq \geq tbl\_seq_{m_i}$, m_i stores $tbl\_update.seq$ into $tbl\_seq_{m_i}$.
     – For each $m_{ent} \in tbl\_update.add$, if a next hop for m_{ent} in a routing table of m_i is not m_{nbr}, an entry for m_{ent} is added where a next hop is m_{nbr}. Otherwise, m_{ent} is removed from $tbl\_update.add$.
     – For each $m_{ent} \in tbl\_update.del$, if a next hop for m_{ent} in a routing table of m_i is m_{nbr}, an entry for m_{ent} is deleted. Otherwise, m_{ent} is removed from $tbl\_update.del$.
     – If $tbl\_update.add \neq \phi$ or $tbl\_update.del \neq \phi$, m_i sends the *tbl_update* to a next hop for a default route. Otherwise, m_i does not send any *tbl_update*.
   - Otherwise, m_i does not send the *tbl_update*. □

According to this step, a message from a mobile computer in C to a computer out of C is forwarded to g_{i+1} by using multi-hop transmission in C. In addition, due to the limited transmission of *gw_chg* message, necessary and sufficient routing tables are updated.

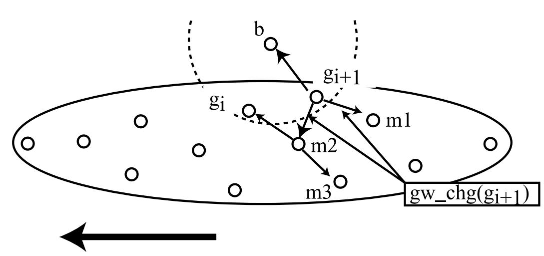

Figure 6: Updating of routing tables.

3.3 Ending of Communication

If a gateway g_n in a cluster C for a base station b gets out of a transmission range of b without receiving

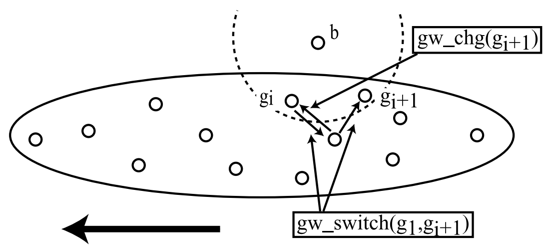

Figure 7: Switching of gateway.

a *gw_chg* message, communication between C and b is finished. Until communication between C and another gateway b' becomes possible due to changing a location of C, i.e. movement of mobile computers in C, no messages are transmitted out of C. According to the discussed "Beginning of Communication" protocol, when communication between C and b' starts, routing table is updated by flooding of a $gw\_chg(g_1')$ message where g_1' is the first gateway for b' and messages destined to a computer out of C is transmitted through g_1'. In order to reduce time overhead for transmitting the messages through g_1', a gateway is switched from g_n to a *pseudo-gateway* g_1. While any mobile computer in C is out of transmission ranges of b and b', messages destined to a computer out of C is buffered by g_1. Though it is impossible to decide the first gateway for b' without receiving a *gw_req* message from b', it is likely that g_1 also becomes the first gateway for b', i.e. $g_1' = g_1$, since relative velocity among mobile computers in C is assumed to be small. Even if $g_1' \neq g_1$, a hop count for forwarding the buffered messages gets reduced.

[**Gateway Switching Protocol**]

1. A gateway g_n in a cluster C for a base station b finds that g_n gets out of a transmission range of b due to no receipt of a *gw_req* message for longer than a certain time interval τ and does not receive a *gw_chg* message, g_n transmits a $gw\_fin(g_n, g_1)$ message to the first gateway g_1 for b by using multi-hop transmission in C. Here, g_n is able to get an address of g_1 since the address is piggied back to *gw_chg* messages.
2. On receipt of a $gw\_fin(g_n, g_1)$ message, g_1 broadcasts a $gw\_chg(g_1)$ message to all mobile computers within a transmission range of g_1. Here, $gw\_chg(g_1).seq := 0$, $gw\_chg(g_1).up := null$ and $gw\_chg(g_1).down$ contains all mobile computers stored in a routing table of $gw\_chg(g_1)$ as destination mobile computers.
3. On receipt of a $gw\_chg(g_1)$ message from a mobile computer m_{nbr}.
   - If $tbl\_seq_{g_i} \neq 0$, $tbl.seq_{g_i} := 0$ and broadcasts the $gw\_chg(g_1)$ message to all mobile computers within a transmission range of g_i according to step 1 of the table updating protocol since a next hop for a default route is $b \neq m_{nbr}$. g_i updates a routing table as that a message destined to a computer out of C is forwarded to m_{nbr} according to the steps of the table updating protocol.
   - Otherwise, g_i follows step 1 of the table updating protocol.

[**Table Updating Protocol**]

1. On receipt of a $gw\_chg(g_1)$ message with $gw\_chg(g_1).seq = 0$ from a mobile computer m_{nbr}.
   - If $tbl.seq_{m_i} \neq 0$, $tbl.seq_{m_i} := 0$.
     - If a next hop for a default route, i.e. the next hop for a computer out of C, is not m_{nbr}, m_i updates a routing table as that m_{nbr} is a next hop for a default route and broadcasts the $gw\_chg(g_1)$ to all mobile computers within a transmission range of m_i after the following modification: $gw\_chg(g_1).up := m_{nbr}$ and $gw\_chg(g_1).down$ contains all mobile computers stored in a routing table of m_{nbr} as destination mobile computers.
     - Otherwise, m_i dose not broadcast the message.
   - Otherwise, i.e. $tbl.seq_{m_i} = 0$.
     - If $gw\_chg(g_1).up = m_i$, m_i adds entries for all mobile computers in $gw\_chg(g_1).down$ whose next hop is m_{nbr} to a routing table of m_i. m_i sends a *tbl_update* message to a next hop for default route. Here, $tbl\_update.seq := 0$, $tbl\_update.add := gw\_chg(g_1).down$ and $tbl\_update.del := \phi$.
     - If $gw\_chg(g_1).up \neq m_i$ and m_i is included in a routing table of m_i as a destination mobile computer, m_i deletes all entries whose next hop is m_{nbr} from a routing table of m_i. m_i sends a *tbl_update* message to a next hop for a default route. Here, $tbl\_update.seq := 0$, $tbl\_update.add := \phi$ and $tbl\_update.del$ contains all mobile computers which deleted from a routing table of m_i in this step.
     - Otherwise, m_i does not send any *tbl_update*.
2. On receipt of a *tbl_update* message from a mobile computer m_{nbr}.
   - For each $m_{ent} \in tbl\_update.add$, if a next hop for m_{ent} in a routing table of m_i is not m_{nbr}, an entry for m_{ent} is added where a next hop is m_{nbr}. Otherwise, m_{ent} is removed from $tbl\_update.add$.
   - For each $m_{ent} \in tbl\_update.del$, if a next hop for m_{ent} in a routing table of m_i is m_{nbr}, an entry for m_{ent} is deleted. Otherwise, m_{ent} is removed from $tbl\_update.del$.
   - If $tbl\_update.add \neq \phi$ or $tbl\_update.del \neq \phi$, m_i sends the *tbl_update* to a next hop for a default route. Otherwise, m_i does not send any *tbl_update*.

4 Evaluation

This section evaluates performance of CB-WSCP by bandwidth between a mobile computer m and a base station b and number of control messages exchanged to update routing tables in m and b compared with DSDV.

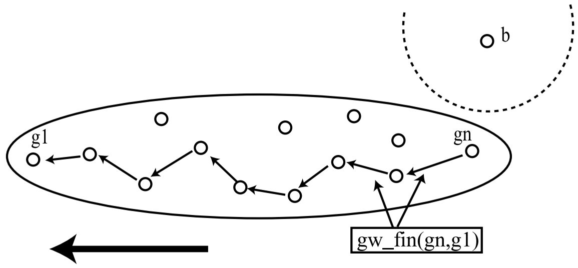

Figure 8: Ending of communication.

First, achieved bandwidth between a base station and a cluster, i.e. mobile computers in a cluster included in a message transmission range of the base station, is evaluated. Here, IEEE802.11b is applied as a wireless LAN protocol. There are 6 mobile computers in a cluster C where distance between two neighbour mobile computers is in accordance with normal distribution $N(\mu, \sigma^2)$ where $\mu = 80$m and $\sigma = 20$m. An effective bandwidth between m and b depends on distance between m and b due to retransmission of lost messages. The relation between distance and an effective bandwidth is shown in Figure 9. Under the above

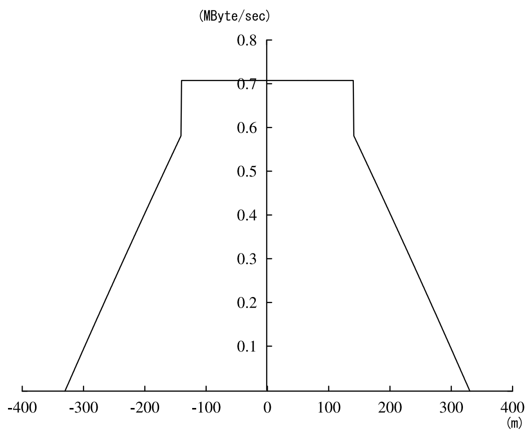

Figure 9: Relation between distance and bandwidth.

assumptions, we compare bandwidth between b and C in cases with DSDV and CB-WSCP. Figures 10 and 11 show simulation results in DSDV and CB-WSCP, respectively. In the case of DSDV, due to occurrences of contentions and collisions, bandwidth is not stable and 28% more messages are transmitted than one-to-one direct communication. On the other hand in CB-WSCP, since only a gateway communicates with b, bandwidth is stable. However, in CB-WSCP, on entering into a message transmission range of a base station, a mobile computer becomes a gateway even though a current gateway is nearer to the base station, i.e. communicates with higher bandwidth. Hence, only 22% more messages are transmitted as shown by a solid line in Figure 11. By using receipt power of messages as a metric for decision to switch a gateway, maximally 92% more messages are transmitted, which is 50% more than DSDV.

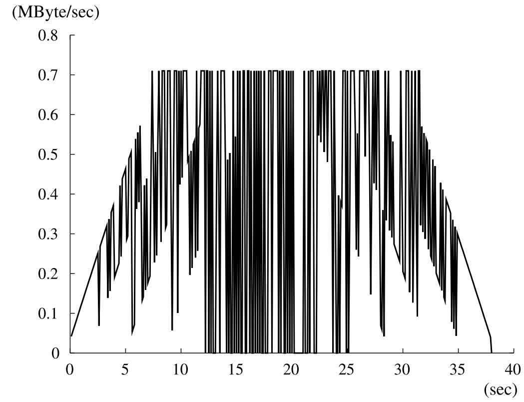

Figure 10: Bandwidth in DSDV.

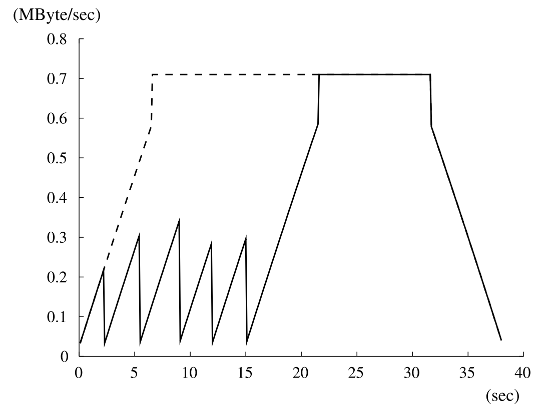

Figure 11: Bandwidth in CB-WSCP.

Figure 12 shows an effect of only one gateway in CB-WSCP. In DSDV, multiple mobile computers might be next hops to/from a base station. Hence, more contentions and collisions occur than CB-WSCP with only one gateway to/from the base station. Figure 12 tells that the more mobile computers communicate with a base station, the less throughput is achieved. Hence, it is reasonable for achieving higher bandwidth to reduce a number of gateway mobile computers to 1.

Next, we compare numbers of control messages to update routing tables. Here, 30 mobile computers are included in a cluster with unique distribution. In DSDV, each time a mobile computer moves into and out of a transmission range of a base station, control messages are transmitted in order to keep a routing table in each mobile computer up to date. However, in CB-WSCP, only when a mobile computer moves into a transmission range of a base station, control messages are transmitted. Hence, as shown in Figure 13, CB-WSCP requires fewer number of control messages than DSDV.

Finally, we evaluate efficiency of a protocol to switch a gateway after finishing communication with a certain base station. For preparing communication with a next base station, a gateway is switched to a mobile computer nearer to the top of a cluster in CB-WSCP.

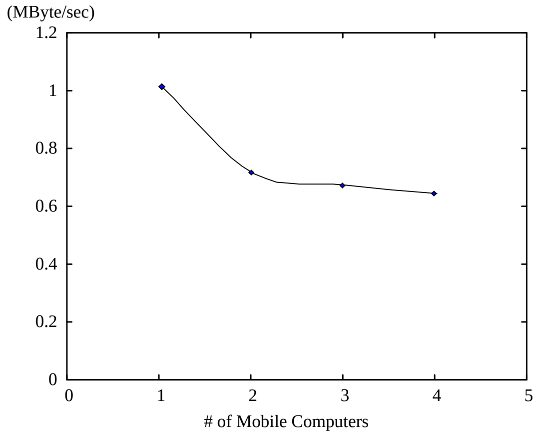

Figure 12: Bandwidth between Base Station and Cluster.

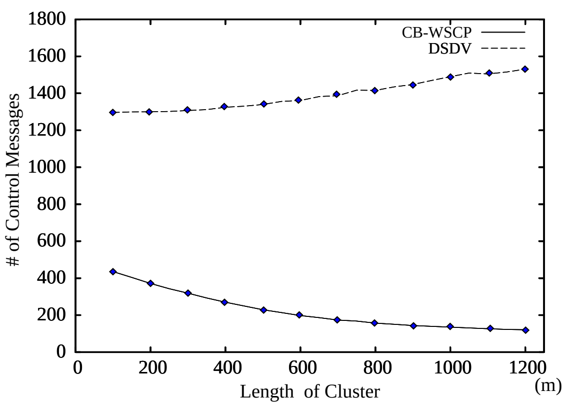

Figure 13: Numbers of Control Messages.

While the cluster is not able to communicate with another computer since no base station is in transmission ranges of mobile computers in the cluster, messages destined to a computer out of the cluster are buffered and transmitted after detection of a new gateway. By using our protocol, no time is required to restart message transmission. However, if the last gateway for a base station continues to serve a role of a gateway, time in Figure 14 is required to restart message transmission after suspension.

5 Concluding Remarks

This paper has proposed CB-WSCP for supporting sporadic communication between a base station and a cluster of mobile computers. In order to achieve a wider effective bandwidth even in the case of high speed mobility, gateway switching is realized in our protocol. In addition, by evaluation of the protocol, it becomes clear that modification of timing control of gateway switching is needed.

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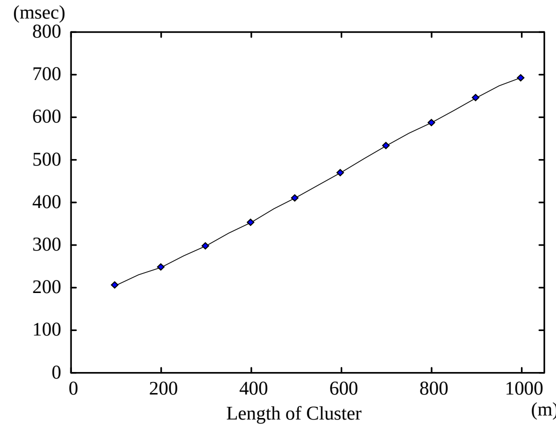

Figure 14: Time Overhead for Restart of Transmission.

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