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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

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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。

## 1 Background and Objective

Recently, mobile computers not only handheld, laptop and parmtop 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 $\langle m_0(=m), \dots, m_n(=b)\rangle$ where $m_{i+1}$ is in a transmission range of $m_i$ $(i = 0, \dots, n-1)$ and $m_{i-1}$ is in a transmission range of $m_i$ $(i = 1, \dots, n)$. Here, a routing protocol for transmitting a message between $m$ and $b$ is required. That is, a mobile computer is required to serve 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], 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 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.

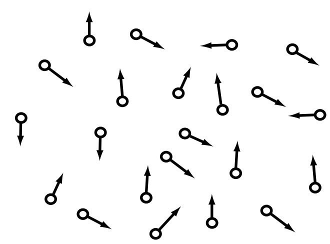

Figure 1: Autonomous mobile computer network.

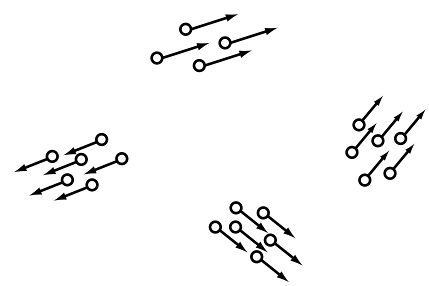

Figure 2: Clustered mobile computer network.

## 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 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.

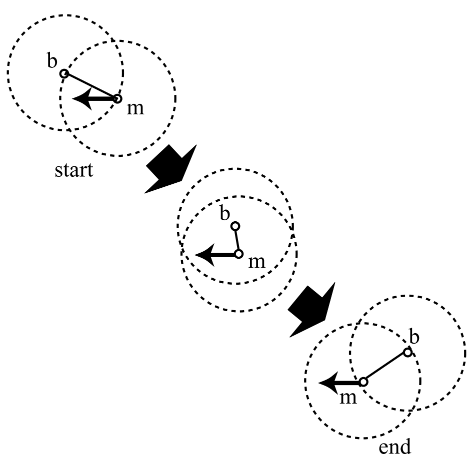


Figure 3: Mobile computer based communication.

## 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-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.

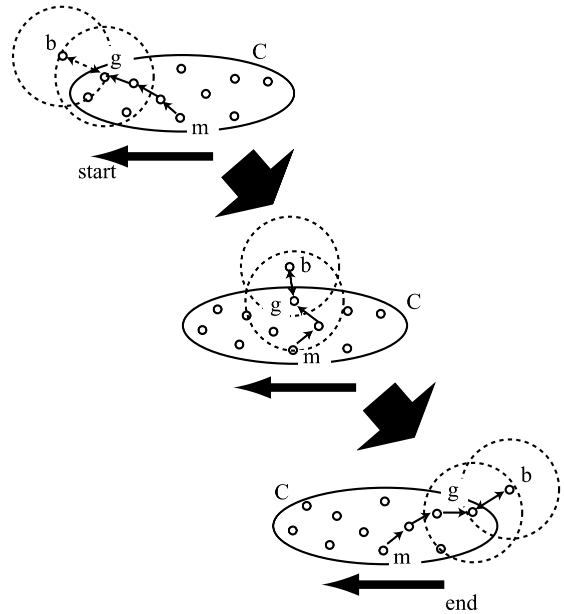


Figure 4: Cluster based communication.

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 $\tau_b$. 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.

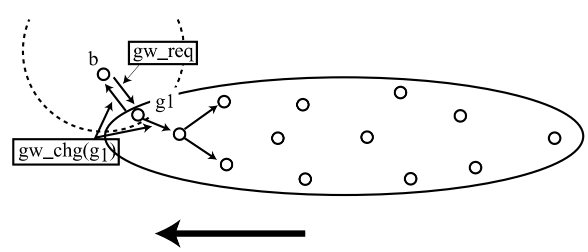


Figure 5: Beginning of communication.

### 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 modefication: $gw\_chg(g_{i+1}).up := m_{nbr}$ 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.

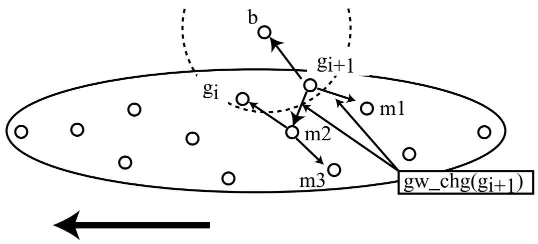


Figure 6: Updating of routing tables.

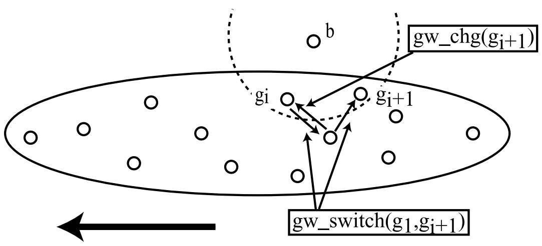


Figure 7: Switching of gateway.

### 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 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 $\tau$ 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 modefication: *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*.

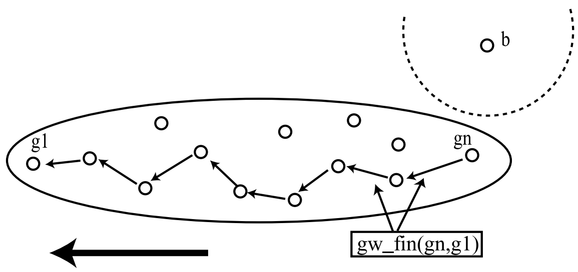


Figure 8: Ending of communication.

## 4 Evaluation

This section evaluates CB-WSCP by bandwidth between a mobile computer $m$ and a base station $b$ comparing with direct communication. 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 $\mu = 80m$ and $\sigma = 20m$. An effective bandwidth between $m$ and $b$ is depend on distance between $m$ and $b$ due to retransmissions of lost messages. The relation between distance and an effective bandwidth is shown in Figure 9. Under the above assumptions, we compare bandwidth between $C$ and $b$ in the following three cases:

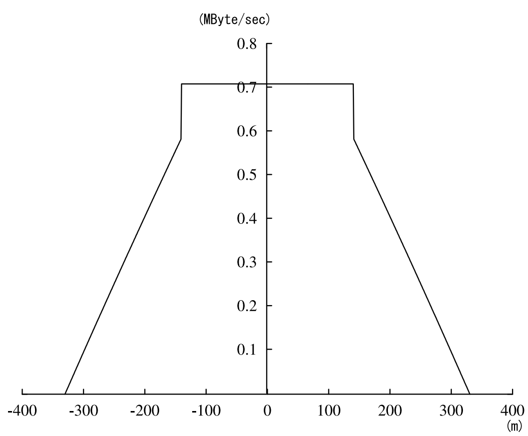


Figure 9: Relation between distance and bandwidth.

- Conventional: Each mobile computer in $C$ communicates with $b$ independently of the other mobile computers in $C$ (Figure 10).
- Proposed: $C$ communicates with $b$ by using CB-WSCP (Figure 11).
- Extended: $C$ communicates with $b$ by using modified CB-WSCP in which the nearest mobile computer to $b$ serves a role of gateway (simulation) (Figure 12).

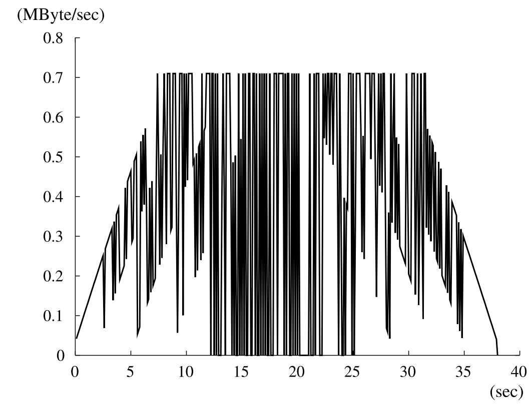


Figure 10: Bandwidth (conventional)

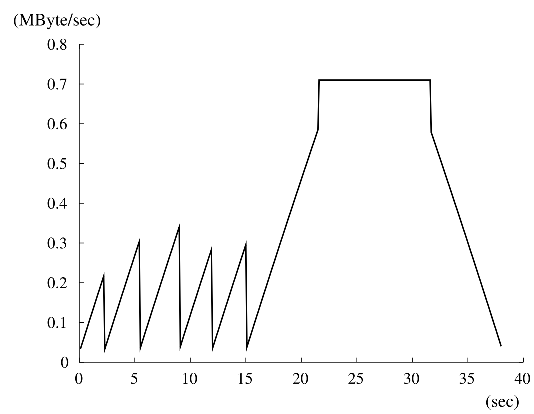


Figure 11: Bandwidth (proposed)

In the conventional method, due to contention and collision, bandwidth is not stable and 28% more messages are transmitted compared with one-to-one (in case of only one mobile computer) communication. In the proposed method, since only a gateway communicates with $b$, bandwidth is stable. However, due to timing of switching of gateway, only 22% more messages are transmitted. In the extended method, 92% more messages are transmitted. Hence, the proposed protocol should be modified in timing of gateway switching.

## 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

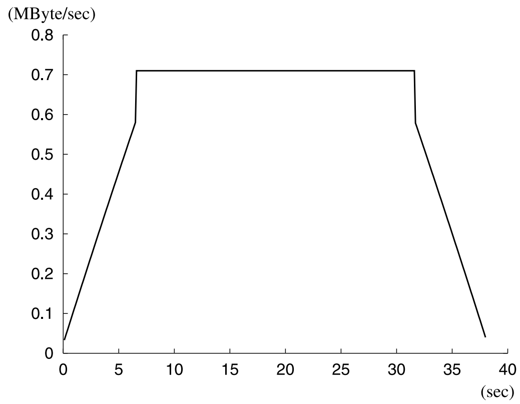


Figure 12: Bandwidth (extended)

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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