

## Sporadic Communication Protocol between Clusters of Mobile Computers

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A cluster of mobile computers consists of multiple mobile computers accessible with each other by wireless multihop message transmission and whose relative speed is low. Here, it is difficult for mobile computers in different clusters to achieve stable wireless multihop transmission route especially with low density of clusters and high relative speed between clusters. In order to achieve higher throughput between clusters while they are reachable, this paper proposes CC-WSCP protocol by which gateway mobile computer through which data messages are transmitted to and from a neighbor cluster is dynamically switched due to mobility of clusters and routing tables within a cluster are updated with lower communication overhead. In simulation, by CC-WSCP, 11.4% less control messages are required for routing table maintenance and 232% more data messages are exchanged between clusters than DSDV which treats all mobile computers in neighboring clusters as those in one ad-hoc network.

### 移動コンピュータ群のための間欠的通信プロトコルとその性能評価

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相対速度が小さく、継続的に無線マルチホップ配送が可能である状態を保ちながら移動するコンピュータ群における通信を考える。同一の移動コンピュータ群に含まれる移動コンピュータ間では安定したマルチホップ通信が可能である一方、異なる移動コンピュータ群に含まれる移動コンピュータ間においては、その相対速度の大きさによって必ずしも安定したマルチホップ通信を行なうことが出来ない。特に、移動コンピュータ群の密度が低く、移動コンピュータ群が高速に移動する場合、マルチホップ通信可能な限られた時間内により大量のデータを交換するためには、経路制御メッセージのオーバーヘッドを削減することが求められる。本論文では、隣接する移動コンピュータ群間の通信をその相対位置によって動的に決定されるゲートウェイ移動コンピュータを介して行なう CC-WSCP プロトコルを提案する。CC-WSCP プロトコルは、移動コンピュータ群の移動による相対速度の変化に伴うゲートウェイの動的な変更とそれに伴う群内ルーティングの変更を行なう。シミュレーション実験により、隣接する 2 つの群全体に対して DSDV を用いる場合と比較して 11.4% の制御メッセージを削減し、232% 多くのデータメッセージを群間で配送することを明らかにした。

## 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 automobiles 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 addition, multiple mobile computers communicate, i.e. exchange messages, with

each other in peer-to-peer network applications. In order for exchanging messages 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 [1] and HIPER-LAN [2] 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* [22]. 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 message 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) [6] and MobileIP [14].

In a multihop-access network, if a mobile computer  $m$  is in a message 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 message 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 message transmission range of  $m_i$  ( $i = 0, \dots, n-1$ ) and  $m_{i-1}$  is in a message 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 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 message 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. 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 [9], DSDV [15], AODV [16] and LBSR [17], for supporting such networks have been proposed.

In a clustered mobile computer network, the network is composed of multiple *clusters* of mobile computers. Each cluster consists of multiple mobile com-

puters 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.

In [10], a routing protocol CB-WSCP (Cluster-to-Base Station Wireless Sporadic Communication Protocol) for supporting communication between a cluster of mobile computers with high-speed mobility and a base station is proposed. 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  $|\vec{v}| < v_{th}$  for a certain threshold value  $v_{th}$  determined by characteristics of a wireless communication system and a network application, sufficient number of messages might be exchanged between  $m$  and a base station  $b$  while  $m$  is in a message transmission range of  $b$ . However, if  $m$  changes a location with a high speed  $|\vec{v}| \geq v_{th}$ , 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. CB-WSCP is a protocol for supporting sporadic communication and achieving transmission of more messages between a base station and a mobile computer in a cluster changing locations with high speed. In this paper, we propose an extended routing protocol of CB-WSCP, CC-WSCP (Cluster-to-Cluster Wireless Sporadic Communication Protocol) for supporting sporadic communication between mobile computers in order to exchange larger amount of messages in a peer-to-peer mobile network application.

## 2 Related Works

For routing a message by multi-hop transmission in a mobile wireless 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; *on-demand routing protocols* and *topology management routing protocols*. By using the former, 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 [9], AODV [16] and LBSR [17] are on-demand routing protocols. Though these protocols are designed to support mobility and limited battery capacity of mobile com-

puters, 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. On the other hand, by using the latter, a routing table in each mobile computer is kept up to date to reflect any changes of a network topology. DSDV [15] is the most popular topology management protocol. This is a kind of a distance vector based routing protocol. In order to inform update of routing information of mobile computers soon after change of network topology, triggered update is applied. Hence, on required to transmit a message by an application, a mobile computer transmit an application message since an up-to-date routing table is kept in each mobile computer.

In order to reduce route discovery and route maintenance overhead in a multihop-access network and an ad-hoc network, cluster-based routing protocols have been proposed. A cluster is a set of mobile computers. In CBRP (Cluster Based Routing Protocol) [3, 8], ULSR (Uni-directional Link State Routing) [11] and Spine Routing [5, 19], 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. For instance, a dynamic cluster configuration method is proposed in [13] in order to reduce the required construction and maintenance overhead and a routing protocol Hi-TORA based on this method is also designed in [12]. 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.

### 3 CC-WSCP

As shown in Figure 1, two mobile computers  $m_i$  and  $m_j$  communicate with each other directly only while  $m_i$  is in a message transmission range of  $m_j$  and vice versa. On the other hand, in a multihop message transmission environment without base stations,

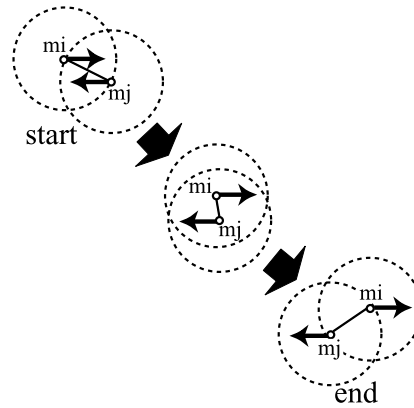


Figure 1: Mobile computer based communication.

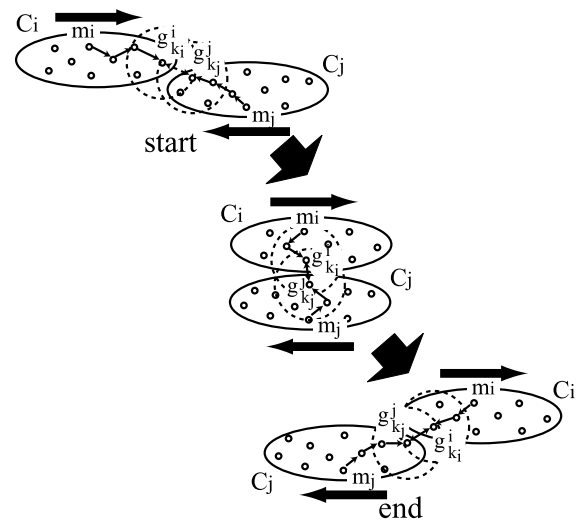


Figure 2: Cluster based communication.

i.e. in an ad-hoc network, if  $m_i$  and  $m_j$  are included in clusters  $C_i$  and  $C_j$  of mobile computers, respectively, more messages are exchanged between  $m_i$  and  $m_j$  while there is a message transmission route between  $m_i$  and  $m_j$ , i.e. at least one pair of mobile computers in  $C_i$  and in  $C_j$  directly exchange messages. However, if a conventional topology management routing protocol is applied, each mobile computer has to keep  $|C_i| + |C_j|$  routing information up-to-date even though relative speed between  $C_i$  and  $C_j$  is high and duration of communication between  $C_i$  and  $C_j$  is not so long, i.e. in a sporadic communication environment.

In order to solve this problem, this paper proposes a novel routing protocol CC-WSCP, cluster-to-cluster wireless sporadic communication protocol. Here, in each cluster of mobile computers, there is one gateway mobile computer to transmit messages from a mobile computer in the cluster to another mobile computer in a neighbor cluster. Hence, for supporting transmission of a message destined to the neighbor cluster, only one

entry to forward the message to the gateway mobile computer is required in a routing table in each mobile computer. Different from CB-WSCP supporting communication between mobile computers in a cluster and a base station, two gateway mobile computers are required in CC-WSCP; one is a transmission gateway and the other is a receipt gateway. CC-WSCP contains functions for detecting the first gateways when at least one mobile computer moves into a message transmission range of one of mobile computers in another cluster of mobile computers, switching gateways as relative mobility of these clusters to continue communication between these clusters and updating routing tables in mobile computers in the cluster to transmit a message destined to a mobile computer out of the cluster. In order to explain the concept and basic idea of CC-WSCP, we first define a cluster of mobile computers.

#### [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  $\langle m_0(=m), \dots, m_n(=m') \rangle$  ( $m_i \in C$ ) of mobile computers where  $m_{i+1}$  is in a transmission range of  $m_i$  ( $i = 0, \dots, n-1$ ) and  $m_{i-1}$  is in a transmission range of  $m_i$  ( $i = 1, \dots, n$ ).  $\square$

#### [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  $m_i \approx m_j$ .  $\square$

If multiple mobile computers in a cluster  $C_i$  independently and autonomously communicate with computers in another cluster  $C_j$ , throughput between  $C_i$  and  $C_j$  is reduced due to occurrences of contentions and collisions in a wireless LAN protocol such as IEEE802.11 based on CSMA/CA. Especially if relative speed between  $C_i$  and  $C_j$  is high, it is critical to avoid occurrences of contentions and collisions since the time duration in which messages are exchanged between  $C_i$  and  $C_j$  is short. Hence, in CB-WSCP, at most one mobile computer in a cluster serves a role of a gateway. Here, only gateway in the cluster is switched according to mobility of the cluster. Here, a gateway is defined as follows.

#### [Gateway in CB-WSCP]

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 a role of a gateway for  $b$ .  $\square$

Suppose that mobile computers  $m_i$  and  $m_j$  are selected as gateways in clusters  $C_i$  and  $C_j$ , respectively.

Here  $m_i$  and  $m_j$  directly exchange messages between these clusters. Due to relative mobility of  $C_i$  and  $C_j$ ,  $m_i$  and  $m_j$  detect almost simultaneously to switch gateway in their own clusters. Here, let  $m_i'$  and  $m_j'$  be next gateways in  $C_i$  and  $C_j$ , respectively. According to the definition of a gateway,  $m_i'$  and  $m_j'$  are in message transmission ranges of the previous gateways  $m_j$  in  $C_j$  and  $m_i$  in  $C_i$ , respectively. This is because mobile computers in  $C_i$  have not yet been informed the switch of a gateway in  $C_j$  and mobile computers in  $C_j$  have also not yet been informed the switch of a gateway in  $C_i$ . In this case,  $m_i'$  is not always in a message transmission range of  $m_j'$  and  $m_j'$  is also not always in a message transmission range of  $m_i'$ . Hence, for a certain duration until  $m_i'$  and  $m_j'$  moves into a message transmission range of the other, communication between  $C_i$  and  $C_j$  is suspended. Therefore, throughput between  $C_i$  and  $C_j$  might be reduced due to this communication suspension.

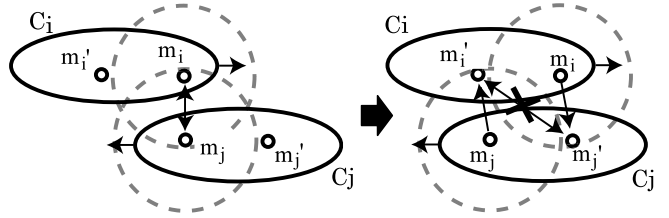


Figure 3: Communication Suspension during Switch of Gateways.

In order to solve this problem, in CC-WSCP, two gateways, i.e. a transmission gateway and a receipt gateway, are introduced.

#### [Gateways in CC-WSCP]

A message destined to a mobile computer out of a cluster  $C_i$  of mobile computers are forwarded to a transmission gateway  $tgw_i$  of  $C_i$  based on routing tables in mobile computers in  $C_i$ . Then, the message is forwarded from  $tgw_i$  to a receipt gateway  $rgw_j$  in a neighbor cluster  $C_j$ .  $rgw_j$  is in a message transmission range of  $tgw_i$ . If  $rgw_j$  moves out to a transmission range of  $tgw_i$  due to relative mobility between  $C_i$  and  $C_j$ , not both but either of the gateways  $tgw_i$  or  $rgw_j$  is switched to continue communication between  $C_i$  and  $C_j$ .  $\square$

In CC-WSCP, for communication between clusters  $C_i$  and  $C_j$  of mobile computers, receipt gateways  $rgw_i \in C_i$  and  $rgw_j \in C_j$  are switched first as changing relative location between  $C_i$  and  $C_j$ . Before a current receipt gateway  $rgw_j$  in  $C_j$  moves out of a message transmission range of a current transmission gateway  $tgw_i$  in  $C_i$ , another mobile computer in  $C_j$  might move in a message transmission range of  $tgw_i$ . That is, multiple mobile computers might be included in a mes-

sage transmission range of a transmission gateway in another cluster. If DSDV protocol is applied, multiple mobile computers in  $C_j$  becomes next-hops of  $tgw_i$  to transmit a message to a mobile computer in  $C_j$ . However, each time a mobile computer in  $C_j$  moves into or out of a message transmission range of  $tgw_i$ , routing information should be updated in  $tgw_i$  and mobile computers in  $C_j$ . In CC-WSCP, on moving into a message transmission range of  $tgw_i$ , a receipt gateway  $rgw_j$  is switched. Hence, number of routing updates in  $tgw_i$  and mobile computers in  $C_j$  is less than number of mobile computers move into a message transmission range of  $rgw_i$ . After last candidates serve transmission gateways in  $C_i$  and  $C_j$ , not receipt gateways but transmission gateways are switched. In this case, it is difficult to detect the fact that a receipt gateway  $rgw_j$  moves into a message transmission range of a mobile computer in  $C_i$  different from a current transmission gateway  $tgw_i$ . In order to detect the fact by  $rgw_j$ , all possible mobile computers to become a transmission gateway are required to transmit a message repeatedly. On the other hand, in order to detect the fact by a new transmission gateway,  $rgw_j$  is required to transmit a message repeatedly. However, it conflicts with an application message transmitted from  $C_i$  to  $C_j$  since  $rgw_j$  serves a role of a receipt gateway. In CC-WSCP, receipt power of a message from  $tgw_i$  is measured in  $rgw_j$  to detect timing to request to switch a transmission gateway in  $C_i$ .

In our proposed protocol, CC-WSCP 11 kinds of control messages are exchanged between mobile computers. For a control message  $m$ ,  $m(add)$  means that an address  $add$  is piggybacked to  $m$ . In addition, for each mobile computer  $m_i$ ,  $tgw\_cand_i$  and  $rgw\_cand_i$  represent that  $m_i$  is a candidate for a transmission gateway and a receipt gateway, respectively.

### 3.1 Beginning of Inter-Cluster Communication

- (1) Let a mobile computer  $a_0^t$  be an initial transmission gateway in a cluster  $A$  of mobile computers. A message destined to a mobile computer out of  $A$  is forwarded to  $a_0^t$  according to routing tables kept by mobile computers in  $A$ .  $a_0^t$  broadcasts a receipt gateway request message  $rgw\_req(a_0^t)$  to all mobile computers within a message transmission range of  $a_0^t$  with an interval  $\tau_s$ .
- (2) On receipt of  $rgw\_req(a_0^t)$ , a mobile computer  $b_k$  in another cluster  $B$  of mobile computers sends a receipt gateway proposal message  $rgw\_prop(b_k)$  to  $a_0^t$  for informing of  $a_0^t$  that  $b_k$  is a candidate for an initial receipt gateway for message transmission from  $A$  to  $B$ . In addition,  $rgw\_cand := false$  in  $b_k$ .
- (3) Multiple mobile computers  $b_k$  in  $B$  might receive the  $rgw\_req(a_0^t)$  simultaneously and send back

$rgw\_prop(b_k)$  to  $a_0^t$ . In order to support such a case, after transmission of  $rgw\_req(a_0^t)$ ,  $a_0^t$  waits for  $rgw\_prop(b_k)$  with a timeout  $\delta (< \tau_s)$ . If  $a_0^t$  receives multiple  $rgw\_prop(b_k)$ ,  $a_0^t$  selects a mobile computer  $b_0^r$  from the mobile computers in  $B$  which send  $rgw\_prop(b_0^r)$  as a receipt gateway in  $B$ .  $a_0^t$  broadcasts a receipt gateway select message  $rgw\_sel(b_0^r)$  to all mobile computers within a message transmission range of  $a_0^t$ . A routing table in  $a_0^t$  is modified as to forward messages destined to a mobile computer out of  $A$  to  $b_0^r$ .

- (4) On receipt of  $rgw\_sel(b_0^r)$ ,  $b_k$  serves an initial receipt gateway for message transmission from  $A$  to  $B$  if  $b_0^r = b_k$ .  $b_k$  sends a receipt gateway registration message  $rgw\_reg(b_k)$  to an initial transmission gateway  $b_0^t$  in  $B$  in order to inform of  $b_0^t$  that  $b_k$  becomes an initial receipt gateway. Otherwise, i.e.  $b_0^r \neq b_k$ ,  $b_k$  does not serve a receipt gateway for communication between  $A$  and  $B$ .

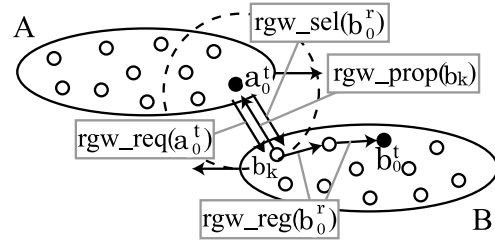


Figure 4: Beginning of Inter-Cluster Communication.

### 3.2 Switch of Receipt Gateway

Due to mobility of clusters  $A$  and  $B$  of mobile computers, a current receipt gateway  $b_i^r$  in  $B$  for message transmission from  $A$  to  $B$  moves out of a message transmission range of an initial transmission gateway  $a_0^t$  in  $A$ . Hence, in order to achieve continuous communication between  $A$  and  $B$ ,  $b_i^r$  delegates another mobile computer  $b_{i+1}^r$  in  $B$ , i.e.  $b_{i+1}^r$  serves a receipt gateway, when  $b_{i+1}^r$  moves into a message transmission range of  $a_0^t$ .

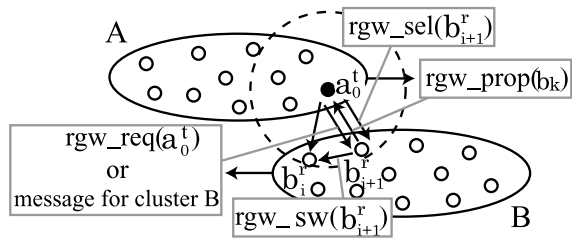


Figure 5: Switch of Receipt Gateway.

- (0) In order to realize switch of a receipt gateway in  $B$ , a current transmission gateway  $a_i^t$  broadcasts  $rgw\_req(a_i^t)$  to all mobile computers in a message transmission range of  $a_i^t$  if  $a_i^t$  does not forward a

message destined to a mobile computer out of  $A$  for an interval  $\tau_c (\ll \tau_s)$ .

- (1) A mobile computer  $b_k$  in  $B$  detects that  $b_k$  moves into a message transmission range of an initial transmission gateway  $a_0^t$  in  $A$  due to receipt of an application message transmitted from  $a_0^t$  to a current receipt gateway  $b_i^r$  in  $B$  and/or receipt of  $rgw\_req(a_0^t)$  broadcasted with an interval  $\tau_c$  by  $a_0^t$ .
- (2) If  $rgw\_cand = true$  in  $b_k$ ,  $b_k$  sends a receipt gateway proposal message  $rgw\_prop(b_k)$  to  $a_0^t$  for informing of  $a_0^t$  that  $b_k$  is a candidate for a next receipt gateway in  $B$  for message transmission from  $A$  to  $B$ . In addition,  $rgw\_cand := false$  in  $b_k$ .
- (3) Multiple mobile computers  $b_k$  in  $B$  might receive the  $rgw\_req(a_0^t)$  simultaneously and send back  $rgw\_prop(b_k)$  to  $a_0^t$ . In order to support such a case, after transmission of  $rgw\_req(a_0^t)$ ,  $a_0^t$  waits for  $rgw\_prop(b_k)$  for an interval  $\delta (< \tau_c)$ . If  $a_0^t$  receives multiple  $rgw\_prop(b_k)$ ,  $a_0^t$  selects a mobile computer  $b_{i+1}^r$  from the mobile computers in  $B$  which send  $rgw\_prop(b_k)$  as a next receipt gateway in  $B$ .  $a_0^t$  broadcasts a receipt gateway select message  $rgw\_sel(b_{i+1}^r)$  to all mobile computers within a message transmission range of  $a_0^t$ . A routing table in  $a_0^t$  is modified as to forward messages destined to a mobile computer out of  $A$  to  $b_{i+1}^r$ .
- (4) On receipt of  $rgw\_sel(b_{i+1}^r)$ ,  $b_k$  serves a next receipt gateway in  $B$  for message transmission from  $A$  to  $B$  if  $b_{i+1}^r = b_k$ .  $b_k (= b_{i+1}^r)$  sends a receipt gateway switch message  $rgw\_sw(b_{i+1}^r)$  to the current receipt gateway  $b_i^r$  in  $B$  in order to inform of  $b_i^r$  that  $b_k$  becomes a next receipt gateway. Here,  $b_{i+1}^r$  achieves an address of  $b_i^r$  by receipt of an application message transmitted from  $a_0^t$  to a current receipt gateway  $b_i^r$  in  $B$  and/or receipt of  $rgw\_req(a_0^t)$  broadcasted by  $a_0^t$  in step (1). Otherwise, i.e.  $b_{i+1}^r \neq b_k$ ,  $b_k$  does not serve a receipt gateway for communication between  $A$  and  $B$ .

### 3.3 Switch of Transmission Gateway

According to the protocol in 3.2, a receipt gateway in  $B$  is switched and message transmission from  $A$  to  $B$  is continued even though mobility of clusters  $A$  and  $B$  of mobile computers. If no mobile computer in  $B$  is in a message transmission range of an initial transmission gateway  $a_0^t$  in  $A$ , i.e. a current receipt gateway  $b_n^r$  in  $B$  is the last mobile computer included in a message transmission range of  $a_0^t$ , it is impossible to continue message transmission from  $A$  to  $B$  by switch of a receipt gateway in  $B$ . However, by introducing a protocol for switch of a transmission gateway in  $A$ , it might be still possible to continue message transmission from  $A$  to  $B$ . Since it is assumed that each mobile computer does not get its relative location in a cluster,  $b_n^r$  detects to be a last receipt gateway in  $B$  by

using receipt power of a message from a transmission gateway  $a_i^t$  (initially  $a_0^t$ ) in  $A$ .

- (1) If receipt power of a message from a current transmission gateway  $a_i^t$ , i.e. an application message from  $A$  to  $B$  and  $rgw\_req(a_0^t)$ , gets lower than a threshold value  $rpw_{th}$  without receipt of a receipt gateway switch message  $rgw\_sw(b_{n+1}^r)$  from a next receipt gateway  $b_{n+1}^r$  in  $B$ ,  $b_n^r$  broadcasts a transmission gateway request message  $tgw\_req(b_n^r)$  to all mobile computers in a message transmission range of  $b_n^r$ .
- (2) On receipt of  $tgw\_req(b_n^r)$ , a mobile computer  $a_k$  in  $A$  sends a transmission gateway proposal message  $tgw\_prop(a_k)$  to  $b_n^r$  for informing of  $b_n^r$  that  $a_k$  is a candidate for a next transmission gateway for message transmission from  $A$  to  $B$  if  $tgw\_cand = true$  in  $a_k$ . In addition,  $tgw\_cand := false$  in  $a_k$ .
- (3) Multiple mobile computers  $a_k$  in  $A$  might receive the  $tgw\_req(b_n^r)$  simultaneously and send back  $tgw\_prop(a_k)$  to  $b_n^r$ . In order to support such a case, after transmission of  $tgw\_req(b_n^r)$ ,  $b_n^r$  waits for  $tgw\_prop(a_k)$  for an interval  $\delta (< \tau_c)$ . If  $b_n^r$  receives multiple  $tgw\_prop(a_k)$ ,  $b_n^r$  selects a mobile computer  $a_{i+1}^t$  from the mobile computers in  $A$  which send  $tgw\_prop(a_k)$  as a transmission gateway in  $A$ .  $b_n^r$  broadcasts a transmission gateway select message  $tgw\_sel(a_{i+1}^t)$  to all mobile computers within a message transmission range of  $b_n^r$ .
- (4) On receipt of  $tgw\_sel(a_{i+1}^t)$ ,  $a_k$  serves a next transmission gateway for message transmission from  $A$  to  $B$  if  $a_{i+1}^t = a_k$ .  $a_k (= a_{i+1}^t)$  broadcasts a transmission gateway switch message  $tgw\_sw(a_{i+1}^t)$  to all mobile computers in a message transmission range of  $a_k$ . Otherwise, i.e.  $a_{i+1}^t \neq a_k$ ,  $a_k$  does not serve a transmission gateway for communication between  $A$  and  $B$ .

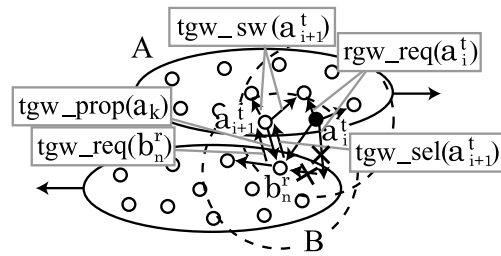


Figure 6: Switch of Transmission Gateway.

### 3.4 Update of Routing Table in Cluster

- (1) On receipt of the first transmission gateway switch message  $tgw\_sw(a_{i+1}^t)$  initiated by  $a_{i+1}^t$  from a neighbor mobile computer  $a_l$ , a mobile computer  $a_k$  in  $A$  updates a routing table to forward messages destined to a mobile computer out of  $A$  to  $a_l$ . Now, if a routing table is modified,  $a_k$  broadcasts

$tgw\_sw(a_{i+1}^t)$  to all mobile computers within a message transmission range of  $a_k$ . Otherwise, i.e. a next hop for a message destined to a mobile computer out of  $A$  is  $a_l$  in a routing table of  $a_k$  before receipt of  $tgw\_sw(a_{i+1}^t)$  from  $a_l$ ,  $a_k$  does not broadcast  $tgw\_sw(a_{i+1}^t)$ .

- (2) After receipt of  $tgw\_sw(a_{i+1}^t)$ ,  $a_i^t$  forwards a received message destined to a mobile computer out of  $A$  not to a receipt gateway  $b_i^r$  in  $B$  but to  $a_{i+1}^t$ . If messages destined to mobile computers out of  $A$  are stored in a message buffer in  $a_i^t$ ,  $a_i^t$  forwards them directly to  $b_i^r$  until all the messages are forwarded or  $b_i^r$  moves out of a message transmission range of  $a_i^t$ . In the latter case, rest buffered messages are also forwarded to  $B$  through  $a_{i+1}^t$ .

### 3.5 Ending of Inter-Cluster Communication

If the last receipt gateway  $b_n^r$  in a cluster  $B$  receives no transmission gateway proposal message  $tgw\_prop(a_k)$  from any mobile computer in another cluster  $A$  even though  $b_n^r$  broadcasts a transmission gateway request message  $tgw\_req(b_n^r)$ , communication between  $A$  and  $B$  becomes impossible, i.e. no pair of mobile computers in  $A$  and in  $B$  exchange messages directly. In order to reduce communication overhead required at the beginning of next inter-cluster communication in  $B$ , messages destined to mobile computers out of  $B$  are required to be buffered in a mobile computer which is likely to serve an initial transmission gateway. By selecting a mobile computer which locates near the top of mobile computer in  $B$ , more messages are exchanged in a next inter-cluster communication. In CC-WSCP, the initial transmission gateway or the initial receipt gateway in the previous inter-cluster communication is selected as the next initial transmission gateway.

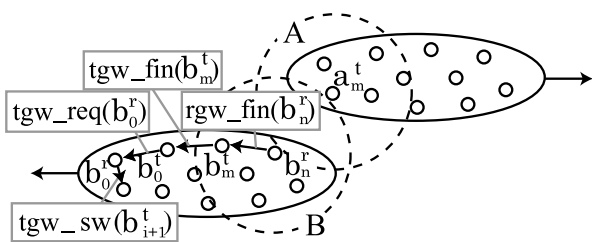


Figure 7: Ending of Inter-Cluster Communication.

- (1) The last receipt gateway  $b_n^r$  in a cluster  $B$  sends a receipt gateway finish message  $rgw\_fin(b_n^r)$  to the last transmission gateway  $b_m^t$  in  $B$ .
- (2) On receipt of  $rgw\_fin(b_n^r)$ ,  $b_m^t$  sends a transmission gateway finish message  $tgw\_fin(b_m^t)$  to the initial transmission gateway  $b_0^t$  in  $B$ .
- (3) On receipt of  $tgw\_fin(b_m^t)$ , if  $rgw\_cand = false$  in  $b_0^t$ ,  $b_0^t$  detects that the initial receipt gateway  $b_0^r$  lo-

ates nearer to the top of  $B$  than  $b_0^t$ . Hence,  $b_0^t$  sends a transmission gateway request message  $tgw\_req(b_0^r)$  to  $b_0^r$ . On receipt of  $tgw\_req(b_0^r)$ ,  $b_0^r$  broadcasts a transmission gateway switch message  $tgw\_sw(b_0^r)$  in order to update routing tables in mobile computers in  $B$  such that messages destined to mobile computers out of  $B$  is forwarded to  $b_0^r$ . Otherwise, i.e.  $rgw\_cand = true$  in  $b_0^t$ ,  $b_0^t$  detects that  $b_0^r$  locates nearer to the top of  $B$  than  $b_0^t$ . Hence,  $b_0^t$  broadcasts a transmission gateway switch message  $tgw\_sw(b_0^t)$  to all mobile computers within a transmission range of  $b_0^t$ .

## 4 Evaluation

In CC-WSCP, routing of message between clusters is based on the concept of clusters. That is, messages to a destination mobile computer in a different cluster from a source one is transmitted through a current transmission and receipt gateways. Hence, each mobile computer is only required to maintain a route to the transmission gateway. On the other hand, DSDV is one of the most important proactive ad-hoc routing protocol. DSDV is designed without the concept of clusters, if mobile computers in two clusters get accessible, all the mobile computers are treated as in the same routing domain. That is, each mobile computer is required to maintain routes to all the other mobile computers in either cluster. Figures 8 and 9 shows numbers of control messages and data messages where two 500m length clusters with 30 mobile computers more with speed of 10-20km/h. Averagely, CC-WSCP requires 11.39% less control messages for maintenance of routing tables and 232.07% more data messages are exchanged between clusters.

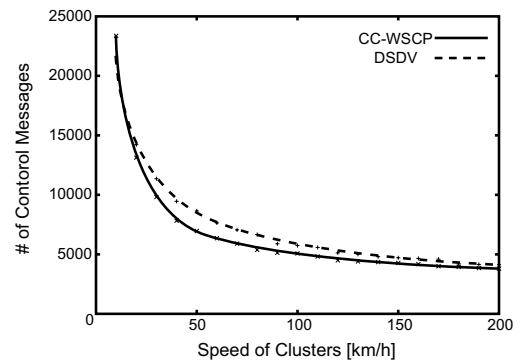


Figure 8: Number of Control Messages

## 5 Concluding Remarks

This paper proposed a novel routing protocol CC-WSCP for supporting mobile computers which communicate with wireless LAN protocols and change their

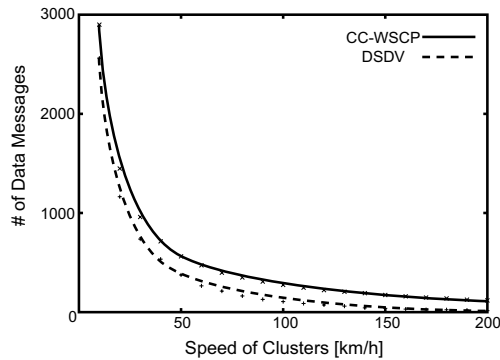


Figure 9: Number of Data Messages

locations based on clustered mobility. Here, two gateways, a transmission gateway and a receipt gateway, engaged in exchange of messages between clusters. These gateways are switched according to relative mobility of the clusters. In CC-WSCP, first a receipt gateway and then a transmission gateway are switched. By using our introduction of two gateways and switching protocol, more messages are exchanged in a sporadic communication environment.

## References

- [1] "Wireless LAN Medium Access control (MAC) and Physical Layer (PHY) Specifications," Standard IEEE 802.11 (1997).
- [2] "Radio Equipment and Systems (RES); HIPERLAN," ETSI Functional Specifications (1995).
- [3] Basu, P., Khan, N. and Little, D.C.T., "A Mobility Based Metric for Clustering in Mobile Ad Hoc Networks," Proceedings of the IEEE International Conference on Distributed Computing Systems Workshops, pp. 413–418 (2001).
- [4] Conta, A. and Deering, S., "Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6)," RFC 2463 (1998).
- [5] Dae, B., Sivakumar, R. and Bharghavan, V., "Routing in Ad Hoc Networks Using a Spine," Proceedings of IEEE International Conference on Computer Communications and Networks (1997).
- [6] Droms, R., "Dynamic Host Configuration Protocol," RFC 1531 (1993).
- [7] Hinden, R. and Deering, S., "IP Version 6 Addressing Architecture," RFC 2373 (1998).
- [8] Jiang, M., Li, J. and Tay, Y.C., "Cluster Based Routing Protocol (CBRP)," IETF Internet-Draft (1999).
- [9] Johnson, D.B. and Maltz, D.A., "Dynamic Source Routing in Ad-hoc Wireless Networks," ACM Computer Communication Review, Vol. 26, pp. 153–181 (1996).
- [10] Kato, C., Harada, S. and Higaki, H., "Wireless Sporadic Communication Protocol for Supporting Cluster-to-Base Station Communication," Proceedings of the IASTED International Conference on Communications and Computer Networks, pp. 311–316 (2002).
- [11] Nishizawa, M., Hagino, H., Hara, T., Tsukamoto, M. and Nishino, S., "A Routing Method Considering Unidirectional Links in Ad-hoc Networks," Transactions of the IPS Japan, vol. 41, No. 3, pp. 783–791 (2000).
- [12] Ohta, T., Fujimoto, M., Inoue, S. and Kakuda, Y., "A Hierarchical Routing Protocol based on Autonomous Clustering in Ad hoc Networks," IEICE Transaction on Communications, Vol. E86-B, No. 10, pp. 2902–2911 (2003).
- [13] Ohta, T., Inoue, S., Kakuda, Y. and Ishida, K., "An Adaptive Multihop Clustering Scheme for Ad Hoc Networks with High Mobility," IEICE Transaction on Communications, Vol.E86-A, No.7, pp. 1689–1697 (2003).
- [14] Perkins, C., "IP Mobility Support," RFC 2002 (1996).
- [15] Perkins, C.E. and Bhagwat, P., "Highly Dynamic Destination-Sequenced Distance Vector Routing (DSDV) for Mobile Computers," Proceedings of ACM SIGCOMM'94, pp. 234–244 (1994).
- [16] Perkins, C.E. and Royer, E.M., "Ad-hoc On-Demand Distance Vector Routing," Proceedings of the IEEE 2nd Workshop on Mobile Computing Systems and Applications, pp. 90–100 (1999).
- [17] Sagawa, Y., Asano, T. and Higaki, H., "Loop-Based Source Routing Protocol for Mobile Ad-hoc Networks," Proceedings of the IASTED International Conference on Communications and Computer Networks, pp. 19–23 (2002).
- [18] Sarikaya, B., "Architectural Requirements for Base Network Mobility Using Bidirectional Tunneling," IETF Internet-Draft(2002).
- [19] Sivakurnar, R., Das, B. and Bharghavan, V., "The Clade Vertebrata: Spines and Routing in Ad Hoc Networks," Proceedings of the IEEE Symposium on Computers and Communications (1998).
- [20] Vijay, D., Wakikawa, R., Alexandru, P. and Pascal, T., "Nemo Basic Support Protocol," IETF Internet-Draft(2003).
- [21] Wakikawa, R., Koshiba, S., Uehara, K. and Murai, J., "Optimized Route Cache Management Protocol for Network Mobility," Proceedings of the 10th International Conference on Telecommunications, pp. 1194–1200 (2002).
- [22] Xiaoyan, H., Mario, G., Guangyu, P. and Ching-Chuan, C., "A group mobility model for ad hoc wireless networks," Proceedings of the 2nd ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems, pp. 53–60 (1999).