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Sporadic Communication Protocol between Clusters of Mobile Computers

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Recently, mobile computers such as laptop, handheld and parmtop PCs have become to communicate with each other by using wireless LAN protocols, e.g., IEEE802.11 and HIPERLAN. Conventional routing protocols support a mobile network in which mobile computers change their location independently. In case that a mobile computer changes a location with high speed, less messages are exchanged between the mobile computers. In this paper, the authors propose a novel routing protocol for supporting mobile clustered networks in which a set of mobile computers move with almost the same velocity and communicate with each other by multi-hop message transmission form a cluster. Here, communication between clusters is available if at least one mobile computer in the cluster is within the message transmission range of a mobile computer in the other cluster. That is, a communication protocol is required to support sporadic communication. For achieving higher bandwidth even though the clusters move with high speed, a set of gateway mobile computers are introduced in each cluster. We design protocols for switching gateways and for updating routing tables in the clusters according to the movement.

モバイルコンピュータ群のための間欠的通信プロトコル

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近年、高性能で低価格のノート型 PC や PDA、自律移動ロボット等の移動コンピュータ間の通信手段として IEEE802.11 や HIPERLAN といった無線 LAN プロトコルの普及が進んでいる。ここでは、移動コンピュータ間の距離が無線信号の到達距離以下であるときにのみ、メッセージの交換が可能である。特に、間欠的通信においては、コンピュータの 移動速度が大きい場合、移動コンピュータ間で交換できるデータ量が小さくなる。このため、マルチメディアデータなどを含むサイズの大きなメッセージを交換するネットワークアプリケーションを実現することができない。本論文では、相対速度が小さく、互いにマルチホップのメッセージ交換が可能である複数のコンピュータをひとつの群 (クラスタ) として管理する新しいルーティングプロトコルを提案する。移動コンピュータ群の密度が低い場合、移動コンピュータ間の通信は、互いに無線信号の到達距離範囲内に位置する時間のみで可能となる間欠的通信となる。ここでは、高速移動コンピュータ群を支援するために、移動コンピュータ群内のマルチホップルーティングとそれぞれの移動コンピュータ群のゲートウェイ間のメッセージ転送および群の移動にともなうゲートウェイ切替機構との組み合わせによって、より大量の情報を交換することを可能としている。本論文では、ゲートウェイ変更プロトコルと群内ルーティングプロトコルについて述べる。

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 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 HIPERLAN [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 $\langle m_0(= m), \ldots, m_n(= b)\rangle$ where m_{i+1} is in a message transmission range of m_i $(i = 0, \ldots, n-1)$ and m_{i-1} is in a message 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 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 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.

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 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. 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.

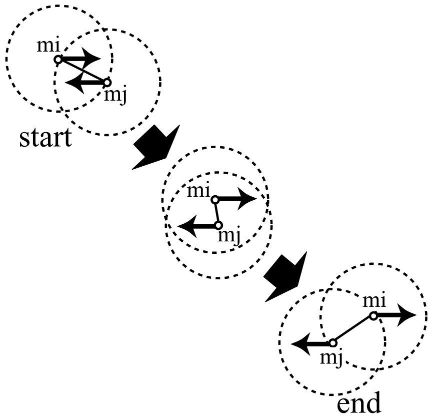

Figure 1: Mobile computer based communication.

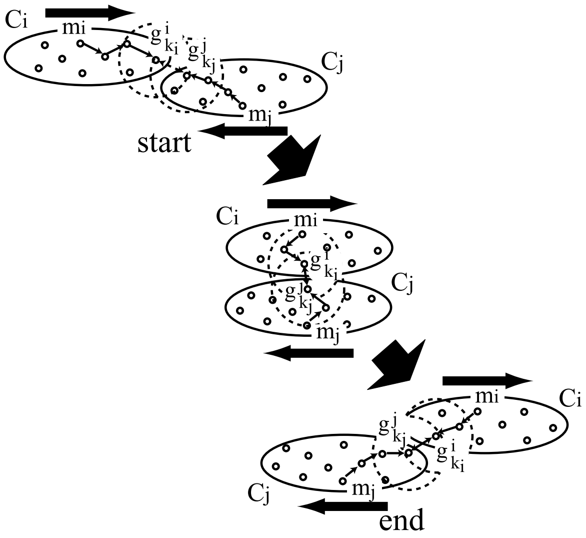

Figure 2: Cluster based communication.

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, 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 $\langle m_0(=m), \ldots, m_n(=m')\rangle$ $(m_i \in C)$ 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_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. □

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_j. 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.

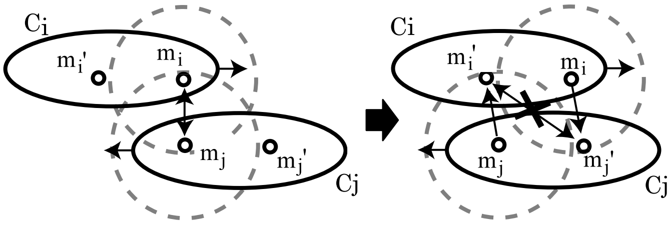

Figure 3: Communication Suspension during Switch of Gateways.

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. □

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 message 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 piggied back 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 τ_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.

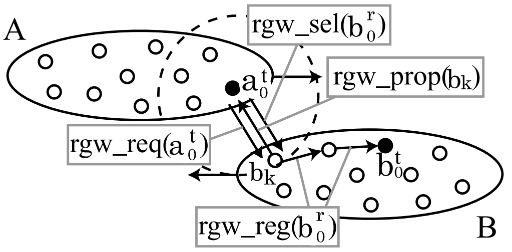

Figure 4: Beginning of Inter-Cluster Communication.

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.

(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

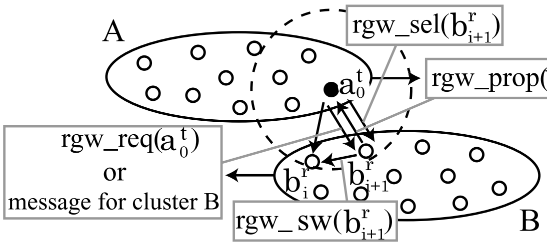

Figure 5: Switch of Receipt Gateway.

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 τ_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^r_{i+1} 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 $rgw\_sel(b^r_{i+1})$ 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^r_{i+1}.

(4) On receipt of $rgw\_sel(b^r_{i+1})$, b_k serves a next receipt gateway in B for message transmission from A to B if $b^r_{i+1} = b_k$. $b_k (= b^r_{i+1})$ sends a receipt gateway switch message $rgw\_sw(b^r_{i+1})$ 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^r_{i+1} 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. $b^r_{i+1} \neq b_k$, 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 $rgw\_sw(b^r_{n+1})$ from a next receipt gateway b^r_{n+1} 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^t_{i+1} 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 $tgw\_sel(a^t_{i+1})$ to all mobile computers within a message transmission range of b_n^r.

(4) On receipt of $tgw\_sel(a^t_{i+1})$, a_k serves a next transmission gateway for message transmission from A to B if $a^t_{i+1} = a_k$. $a_k (= a^t_{i+1})$ broadcasts a transmission gateway switch message $tgw\_sw(a^t_{i+1})$ to all mobile computers in a message transmission range of a_k. Otherwise, i.e. $a^t_{i+1} \neq a_k$, a_k does not serve a transmission gateway for communication between A and B.

3.4 Update of Routing Table in Cluster

(1) On receipt of the first transmission gateway switch message $tgw\_sw(a^t_{i+1})$ initiated by a^t_{i+1} from a neighbor mobile computer a_l, a mobile computer a_k in A updates a routing table to forward mes-

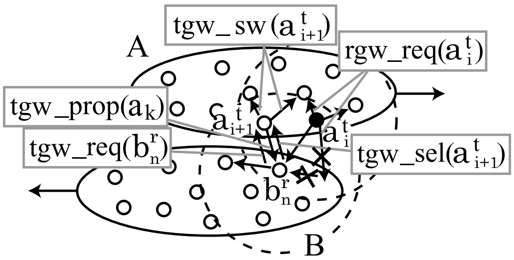

Figure 6: Switch of Transmission Gateway.

sages destined to a mobile computer out of A to a_l. Now, if a routing table is modified, a_k broadcasts $tgw\_sw(a^t_{i+1})$ 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 $tgw\_sw(a^t_{i+1})$ from a_l, a_k does not broadcast $tgw\_sw(a^t_{i+1})$.

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

3.5 Ending of Inter-Cluster Communication

If the last receipt gateway b^r_n 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^r_n broadcasts a transmission gateway request message $tgw\_req(b^r_n)$, 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.

(1) The last receipt gateway b^r_n in a cluster B sends a receipt gateway finish message $rgw\_fin(b^r_n)$ to the last transmission gateway b^t_m in B.

(2) On receipt of $rgw\_fin(b^r_n)$, b^t_m sends a transmission gateway finish message $tgw\_fin(b^t_m)$ to the initial transmission gateway b^t_0 in B.

(3) On receipt of $tgw\_fin(b^t_m)$, if $rgw\_cand = false$ in b^t_0, b^t_0 detects that the initial receipt gateway b^r_0 locates nearer to the top of B than b^t_0. Hence, b^t_0 sends a transmission gateway request message $tgw\_req(b^r_0)$ to b^r_0. On receipt of $tgw\_req(b^r_0)$, b^r_0 broadcasts a transmission gateway switch message $tgw\_sw(b^r_0)$ 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^r_0. Otherwise, i.e. $rgw\_cand = true$ in b^t_0, b^t_0 detects that b^t_0 locates nearer to the top of B than b^r_0. Hence, b^t_0 broadcasts a transmission gateway switch message $tgw\_sw(b^t_0)$ to all mobile computers within a transmission range of b^t_0.

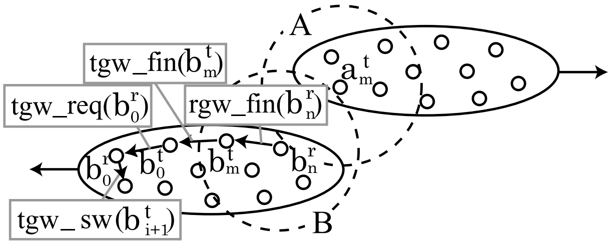

Figure 7: Ending of Inter-Cluster Communication.

4 Evaluation

This section evaluates performance of CC-WSCP by bandwidth between two mobile computers in different clusters C_i and C_j of mobile computers comparing with direct communication. Here, IEEE802.11b is applied as a wireless LAN protocol. There are 50 mobile computers in both clusters C_i and C_j. There mobile computers are uniquely distributed in an area $1000m \times 50m$ of a cluster. An effective bandwidth between two mobile computers m_i and m_j depends on distance between m_i and m_j due to retransmissions of lost messages. Figure 8 shows an example of simulation results. A dotted line represents bandwidth between two mobile computers which exchange messages directly. A solid line represents bandwidth between mobile computers in CC-WSCP. Here, $107.4Mbit$ and $283.4Mbit$ are transmitted, respectively. In 100 simulations, averagely, 2.38 times more messages are transmitted in CC-WSCP. However, Figure 8 also suggests that more messages can be transmitted by modification of switch timing of gateways in clusters.

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

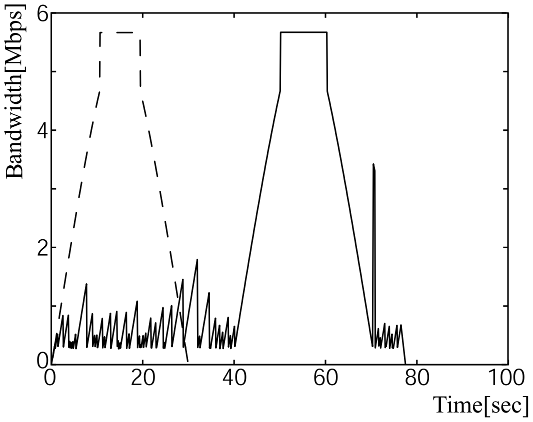

Figure 8: Bandwidth Comparison.

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.

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