A Scalable Multicasting with Group Mobility Support in Mobile Ad Hoc Networks

Kap-Dong Kim*, Kwangil Lee, Jun-Hee Park**, and Sang-Ha Kim*****

Abstract: In mobile ad hoc networks, an application scenario requires mostly collaborative mobility behavior. The key problem of those applications is scalability with regard to the number of multicast members as well as the number of the multicast group. To enhance scalability with group mobility, we have proposed a multicast protocol based on a new framework for hierarchical multicasting that is suitable for the group mobility model in MANET. The key design goal of this protocol is to solve the problem of reflecting the node's mobility in the overlay multicast tree, the efficient data delivery within the sub-group with group mobility support, and the scalability problem for the large multicast group size. The results obtained through simulations show that our approach supports scalability and efficient data transmission utilizing the characteristic of group mobility.

Keywords: *MANET Multicast Protocol, Overlay Multicast, Group Mobility*

1. Introduction

An application uses a multicasting and broadcasting for sending the data to more than one node, because it is more cost-effective than unicast. A mobile ad hoc network (MANET) is a wireless network in which nodes can communicate without infrastructure. Each node operates as a router to forward data. The design of the multicast scheme in MANET is more complex because of the dynamic change in the network topology and the limited bandwidth availability.

Many applications require group-based communications among mobile nodes. Examples include conference seminar sessions, conventional events, disaster relief operations, and battlefield training. To support these applications, many research projects have been studied for group communication in MANET. One of the characteristics of these applications is that the nodes are divided into several sub-groups. That is, nodes that have the same mission achieve it by moving together in the same direction at a fixed distance. For those mobile ad hoc network applications, the mobile ad hoc network requires effective and efficient support for group communications with group mobility using multi-hop and one-to-many nature.

[1] introduced an efficient and scalable multicast protocol called the Multicast-Enabled Landmark Ad hoc Routing Protocol (M-LANMAR). M-LANMAR uses LANMAR [2] as the unicast routing protocol to support the group mobility model. It has an advantage in that the multicast protocol can use the unicast protocol's factors, but M-LANMAR also has the following drawbacks. M-LANMAR uses the proactive mode causing relatively more control overhead in cases where data transmission is paused or where the number of multicast members is lower. It uses inefficient simple scoped flooding for data transmission to the members within the group. In addition, each group receives data directly from the multicast source.

In order to achieve the multicasting with the group mobility, easy deployment, scalability, and low control overhead, a new hierarchical multicasting approach is required. Recent protocols have adopted overlay, location-based, stateless, hierarchy approaches. Multicast protocols [3][4][5] require multicast member and non-member nodes to participate in multicast operations, which increase control and data transmission overhead. But, it is possible to participate in environments where some nodes do not support multicast operations. In such situations, an application-layer multicast protocol [6][7][8] can be deployed easily; it is also flexible and easy to implement. The application-layer multicast monitors only group dynamics, while the underlying unicast protocols track network dynamics, resulting in more stable protocol operation and low control overhead even in a highly dynamic environment [9]. But, the movement of physical nodes cannot affect the update action of the overlay multicast tree because there is no multicast event such as join or leave. A few application-layer multicast protocols such as LGT have tried to solve the transmission overhead resulting from the mismatch between the physical plane and the virtual plane. Also, stateless multicast routing for small groups is proposed to eliminate an overhead of creating and maintaining the delivery tree.

[10] has proposed two classes of hierarchical multicasting approaches to enhance performance and enable scalability. In [10], the first approach, domain-based hierarchical routing, divides a large multicast group into

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Corresponding Author: Kap-Dong Kim

* Agency for Defense Development, Daejeon, Korea (kdkim71@korea. com)
** Digital Home Research Division, ETRI, Daejeon, Korea (leeki@etri.re.kr, juni@etri.re.kr)
*** Dept. of Computer Science, Chungnam National University, Daejeon, Korea (shkim@cnu.ac.kr)

sub-groups, each with a node assigned as a sub-root. The second approach, overlay-driven hierarchical routing, uses the overlay multicast as the upper layer multicast protocol, and stateless small group multicasts as the lower layer multicast protocol.

In this paper, we propose another approach that is suitable for the group mobility model. We have developed a new multicast routing protocol based on another framework for hierarchical multicasting [10] in MANET. A variety of techniques are adopted for effective multicasting to support group mobility. Our approach, that of overlay group-based hierarchical routing, has a static mission group (MG) which moves to the same directional point at a predefined distance among the mission group members (MGM). It uses an LGD-like overlay multicast among the mission group leaders (MGL) as the upper layer multicast protocol, and the stateless small group multicast or a various flood methods as the lower layer multicast protocol.

The remainder of this paper is organized as follows. The next section describes the group mobility model and related research on the multicast protocol. In Section 3 we describe our multicast routing protocol, in Section 4 we present the experimental results of our proposed protocol and, finally, in Section 5, we present the conclusion.

2. Related Work

A group mobility model has been studied by many researchers for several directions, and numerous designs for a routing protocol considering the node mobility have been produced. The hierarchical routing approach can be used to reduce the protocol states in a large scale network. [10] presents two hierarchical multicast approaches, which have the goal of achieving lower multicast overhead and robustness for large-scale multicasting.

2.1 Group Mobility Model

In the ad-hoc network applications scenarios, the mobile nodes show collaborative mobility behavior. A group mobility model can generate such a collaborative mobility behavior. Some researchers have proposed several group mobility models [11][12][13], for the purpose of simulating an ad-hoc network with group motion.

The Reference Point Group Mobility (RPGM) [11] model is a more general group mobility model. Mobile hosts are organized by groups according to their logical relationships. The center's motion defines the entire group's motion behavior, including location, speed, direction, acceleration, and so forth. Usually, nodes are uniformly distributed within the geographic scope of a group. The reference point scheme allows independent random motion behavior for each node, in addition to the group motion.

The Reference Velocity Group Mobility (RVGM) [12] model extends the RPGM model by proposing a velocity representation of the mobility groups and the mobile nodes. Each mobility group has a characteristic group velocity. The member nodes in the group have velocities that are close to the characteristic group velocity, although they deviate slightly from it.

The Reference Region Group Mobility (RRGM) [13] model uses a reference region. A reference region defines an area towards which nodes will move, and once they are within the region, the nodes will move around within that region while waiting for other nodes to arrive. The locations of a reference region define the intermediate points where a group will move along on its way to the destination. The reference region moves gradually towards the destination with its path.

2.2 Multicast Routing Protocol

Multicast routing which adopts a clustering scheme has been studied for a long time. Several multicast protocols have been proposed for the ad hoc networks.

The Multicast routing protocol based on Zone Routing (MZR) [14] is a source-initiated on-demand protocol. It uses the zone routing mechanism to create and maintain multicast trees. A proactive protocol runs inside each zone to maintain an up-to-date zone routing table. The node constructs a zone around itself with a pre-configured zone radius. The protocol reaction to the changes in topology is localized to a zone. Only the nodes within the given zone are affected. As the zone's radius is smaller, the cost of learning the zones' topologies is higher.

The Hierarchical DDM (HDDM) [10] adopts a topology-aware approach. The problem of HDDM is how to partition the multicast group into sub-groups. Within each sub-group, a sub-root is selected. Because the number of members enveloped in the packet header is significantly reduced, this scheme solves the scalability problem of basic DDM. However, the sub-groups are frequently changed according to the movement of the nodes.

The Hierarchical region-based Overlay Multicast Architecture (HOMA) [15] uses GPS and a geographical static region. HOMA solves the scalability problem for the large-sized multicast group by dividing the total multicast tree into a region-based global overlay multicast tree for the whole network. The drawback of HOMA is that multicast operations are inefficient when several nodes move to another region together.

M-LANMAR [1] uses LANMAR [2] as the unicast routing protocol to support the group mobility model. The drawback of M-LANMAR is that the LANMAR protocol itself is not used generally in a mobile ad hoc network, but it has the advantage that the multicast protocol can use the factors of the unicast protocol just as it is because the unicast protocol supports group mobility. It aggregates unicast routing table updates and multicast routing maintenance. Thus, it maintains a low multicast protocol overhead because its uses the aggregated unicast routing tables. Because the group membership and multicast routes of M-LANMAR are regularly updated, it achieves constant control overhead regardless of the number of members and multicast groups. In cases where there is no M-LANMAR data transmission or where the number of the multicast group's numbers is few, it has control overhead constantly.

3. HMMP

We propose an HMMP (Hierarchical Mission group-based Multicast Protocol) in this paper. The key design goal of HMMP is to solve the problem of reflecting the node's mobility in the overlay multicast tree, the efficient data delivery in the sub-group with group mobility, and the scalability problem for the large multicast group size. In Fig. 1, HMMP is based on two-tiered multicast routing architectures, which can divide the total multicast tree into a stateless overlay multicast tree (OMT) composed of mission group leaders and a mission group-based multicast tree (MMT) within the mission group. The mainly assumed conditions are that all nodes use GPS, and that any node which wants to be a multicast group member has to send a joint request message with the unicast to the multicast source or leader of the mission groups.

The multicast source divides the multicast group leaders into sub-groups according to the direction, inserts a list of other leader's information in the same direction into the header of the packet, and sends the packet to the nearest leader in each direction. If the leader receives the packet, it delivers the packet to all multicast members within the mission group through the intra-domain multicast protocol. Each mission group leader recursively performs the above process using the node information in the header of the packet. Multicast membership is maintained by the multicast tree between the source and the leader of the mission group with a Join/Leave packet and a location report packet. Each member of the mission group sends a Join/Leave packet and a location report packet to the leader of the mission group.

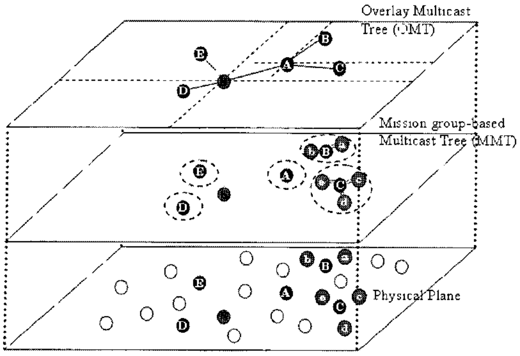

Fig. 1. Two-Tiered Overlay Multicast Architecture

3.1 Overlay Multicast Protocol

The OMT can be constructed with the leader of the mission groups. It can logically reduce the number of multicast member nodes through the hierarchical structure. So, it became easy to compose OMT by applying a suitable, stateless, multicast protocol to a small-sized group. The stateless overlay multicast protocol can eliminate large overhead due to the dynamic network topology, decrease an overhead of creating and maintaining the delivery tree and remove the routing overhead of the non-member nodes. [16] suggests that the overlay multicast is an effective, efficient and practical solution for group communication in MANET using the Location-Guided Tree (LGT) [8], because [16] concluded that LGD has the best balance between bandwidth cost, distribution delay and computational complexity among all the LGT algorithms. We also applied an LGD algorithm to construct an OMT in the upper layer multicast protocol.

In OMP, multicast data is encapsulated in a unicast packet. It is only transmitted to the leaders of the mission groups. A list of leader addresses and geometric locations is explicitly included in the header of the multicast packet to minimize the overall bandwidth cost of the multicast tree. OMP uses only the geometric location information of the leaders of the mission groups. So, OMT does not need to know the global network topology. The transmission of the data packet can be conducted by an underlying unicast routing protocol such as AODV, because [16] discovered that LGD performs better when location information is not accurate. The leader of the mission groups reports a new geometric location only when the current location passes by the predefined boundary from the previous reported location. Such a policy reduces the number of control packets without degrading OMT.

The multicast source divides the multicast member nodes into 4 sub-groups according to 4 directions, establishes the nearest node in each direction by the child node, inserts a list of other nodes' addresses and locations in the same direction into the header of the data packet, and sends the packet to the child node of each direction. Each child node recursively performs the above process with the node information in the header of the data packet. This process stops when a data packet has an empty destination list. Here, OMP selects four as the number of direction because of its convenience regarding directional decisions and the simulation results of [16]. To reduce computational overhead, the leader caches the previously computed tree.

3.2 Group Membership Join

The multicast joining process can be divided into two steps: global and local joining. When a multicast source wants to generate a multicast group, it broadcasts an advertisement message to the whole network with its physical location information and multicast group ID. All nodes in the network learn who the source of the multicast group is. The mission group members with the same mission select a mission group leader and sub-leader. All of the mission group members memorize the leader and sub-leader's address of their mission group. If the request to join is the first from the mission group to a multicast group, the leader of the mission group sends a request to join packet to the source of the multicast group. The mission group's leader maintains a multicast group member list within the mission group, and learns about the location information of the multicast group members. In the event that the leader gives up his role, the sub-leader becomes the leader of the mission group. Thus, the leader sends the multicast group member list information to the sub-leader periodically. For the up-to-date membership, the multicast source uses the location report as the multicast membership refreshments to detect the blind leave node. The leader of the mission group also uses the above process. This process reduces the control message for the multicast membership.

3.3 Group Membership Leave

The multicast leaving process can be divided into two steps: global and local leaving. If a member of the mission group wants to leave the multicast group, it sends a request to leave packet to the leader of the mission group. When the leader receives a request to leave packet from the member of the mission group, it checks the multicast group member list. If the multicast member list is empty, it sends a request to leave packet to the multicast source. There is no leave reply packet in the multicast leaving process. The node sending a request to leave packet must stop in order to send the location report message to the leader or multicast source. Then, the leader or multicast source which does not receive a leave message will exclude the node from the multicast member list after a certain period of time.

3.4 Multicast Tree Maintenance

It is common that groups can be overlapped if they meet each other while moving according to the group mobility. One group can be divided into several groups. But here, in the proposed multicast architecture, the characteristic of the nodes performing the task allocated to the group does not need to consider a merge or a split between groups because one group can only be divided into several temporarily, and two groups can meet for a short time. If the leader of the mission group dies, none of the mission group members can receive data from the multicast source. So, the sub-leader of the mission group checks if the HELLO message has arrived within a threshold of latency. If the sub-leader does not receive a HELLO message within a certain period of time, it assigns itself as the leader of the mission group, advertises this fact to the members of the mission group, and sends a change of leader request message to the multicast source.

3.5 Intra-domain Multicast Protocols

In this section, there is a discussion of which kinds of multicast protocol and unicast protocols are possible within the mission group, and what kinds of dependency exist.

Basically, HMMP can use any multicast routing protocol for an intra-domain multicast within the mission group. From a performance point of view, HMMP is dependent on the underlying routing protocols – unicast and local multicast routing protocols, and the protocols should be selected cautiously. The nodes within the mission groups move according to the same group mobility while maintaining the predefined distance, and have the same mission for a certain period of time. There are many multicast routing protocols, any of which is applicable to the mission group, such as DDM [5], ODMRP [4], LGD [16], and so on. However, considering the characteristics of the mission group, this paper discovers several kinds of new routing algorithms which are suitable for a small mission group with a defined boundary.

The most common broadcasting methods are used to the lower layer multicast protocol. [17] classifies the existing broadcasting schemes into categories. In [17], the protocols are categorized into four families: Simple Flooding, Probability Based Methods, Area Based Methods and Neighbor Knowledge Methods. We can adopt some protocols that are suitable for a small network. Also, we used a concept that is similar to the overlay broadcast scheme. Firstly, the 1-Hop Overlay Broadcast Scheme is used on the multicast group members within the mission group. If the node receives a packet with a new sequence number, it broadcasts a packet with a 1-hop value. Secondly, the Counter-Based 1-Hop Scheme is used on the multicast group members within the mission group. Upon the reception of an unknown packet's sequence number, the node initializes a counter of the packet's sequence number, and sets the Random Assessment Delay (RAD) time. During this time, the counter increases when a packet with the same sequence number is reached. If the counter is more than the pre-defined threshold value when the timer expires, the packet is dropped. This is simple and suitable in a dense area of the network. This scheme utilizes the Counter-Based Scheme discussed in [18] over the overlay network in the mission group. Thirdly, [19] stated that the Self Pruning scheme could be more appropriate when the mobility of the host is high and the network is small. So, this scheme can be adapted to the mission group. Fourthly, the Multicast Region concept [20] can be adapted to the flooding scheme. So, the leader of the mission group can set up the multicast regions in the mission group according to the location of the nodes. Several kinds of multicast region can be optimized.

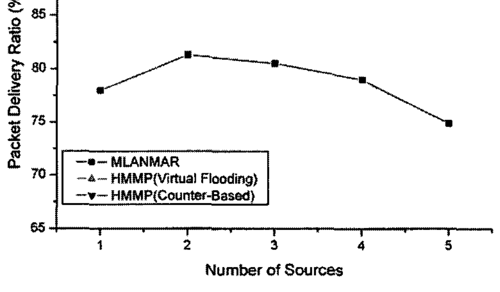

Fig. 2. Packet Delivery Ratio (speed = 5m/s)

4. Performance Analysis by Simulation

4.1 Simulation Model and Parameters

We use the QualNet [21] simulator, which provides a scalable simulation environment for wireless network systems using the parallel discrete-event simulation capability with a model of the MAC, Channel and routing protocols. In this simulation, network size is a 2K by 2K meter squared place, the number of mobile nodes is 250, the transmission range of each node is 238m, each individual node moves in a random way-point pattern, mobility speed is 5/10 meters per second with 2 seconds pause time, all the simulations are carried out for 200 seconds with 10 different seed numbers, and the underlying unicast protocol used is AODV.

Each source generates data in a CBR fashion with UDP, and sends out four packets every second with a 512-byte packet size as the default. We divide the network into 15 mission groups where each group has group mobility following the RPGM model, including 10 nodes and 100 individual moving nodes. We increase the number of multicast groups from 1 to 5, wherein each group has 3 mission groups with a single source and 10 member nodes.

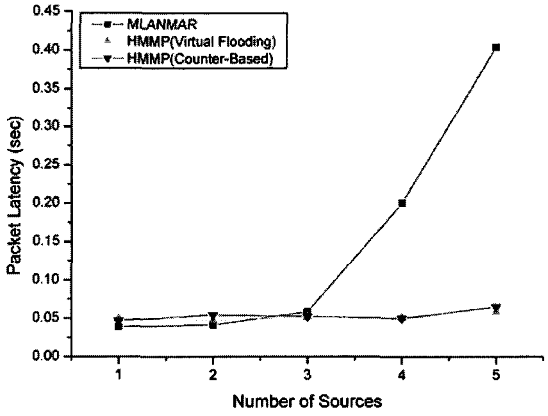

Fig.3. Packet Latency (speed = 5m/s)

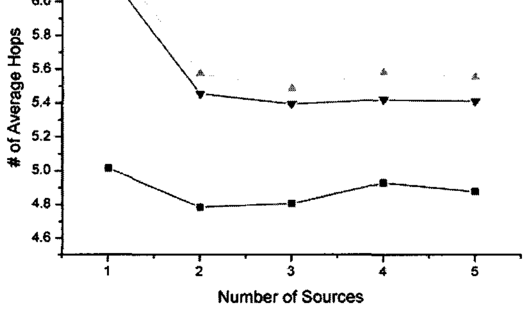

Fig. 4. Average Hop Count (speed = 5m/s)

We will compare several metrics with M-LANMAR, and will also evaluate several broadcast schemes with the mission group.

We use the following metrics for our performance:

(a) Packet Delivery Ratio: The ratio of the number of data packets actually delivered to the destinations to the number of data packets supposed to be delivered. This metric presents the effectiveness of the multicast protocol.

(b) Packet Latency: The average end-to-end delay of a multicast packet to each member node.

(c) Average Hop Count: The average number of hops a data packet travels. The total cost of the multicast tree can be evaluated by this value.

(d) Normalized Control Overhead: The ratio of the number of control packets generated by each node to the number of data packets supposed to be received.

(e) Normalized Forwarding Overhead: The ratio of the number of data packets generated by each node to the number of data packets supposed to be received.

4.2 Simulation Results

We focus on the packet delivery ration and normalized control overhead to present the effectiveness of a protocol, on the average hop count and the end-to-end delay to prove the low tree cost value, and on the normalized forwarding overhead to express the data traffic load on the network.

In Fig. 2, when the number of multicast groups is increased, the packet delivery ratio of the protocols is decreased. M-LANMAR falls quickly, while HMMP - which uses the overlay broadcast scheme and counter-based 1-hop scheme - drops slowly. In any case, when the maximum speed is 20 m/s and 5 multicast groups with 30 group members participate in the multicast, HMMP shows superior performance to M-LANMAR.

In Figs. 3 and 4, as the number of multicast groups increases, the packet latency value of M-LANMAR increases; on the other hand, the packet latency of HMMP maintains a constant value. In M-LANMAR, because the source node directly transmits data to the leader of each sub-group, data can arrive by the shortest path. Therefore, data can be delivered with fewer hops than those of HMMP.

Next, in Figs. 5 and 6, because the multicast routes of M-LANMAR are updated regularly, it achieves constant control overhead regardless of the number of members and multicast groups. So, in the event that the number of members joining a multicast service is less, it causes relatively more control overhead. Because it is in proportion to the number of multicast members, the control overhead of HMMP maintains a constant normalized control overhead. The data forwarding overhead of the HMMP using virtual flooding is lower than M-LANMAR as the use of the overlay broadcast scheme. Moreover, even when the Counter-Based 1-Hop Scheme is adapted, a similar performance is maintained with the data forwarding overhead, which is more of less lower than those of the virtual flooding.

5. Conclusion

In this paper, we developed a scalable multicast protocol with group mobility support in the mobile ad hoc network to improve the performance and protocol efficiency. A new protocol, known as HMMP, constructs a pre-defined mission group with group mobility and a stateless overlay multicast tree among mission group leaders to reduce the routing overhead. Through the simulation experiments, we demonstrated that HMMP performs well with regard to the packet delivery ratio, the packet latency, the control and data forwarding overhead, and the scalability for the number of groups with group mobility. Within the mission group with group mobility, we propose using the overlay broadcast scheme and counter-based 1-hop scheme rather than the multicast and common broadcasting methods. HMMP is based on overlay group-based hierarchical routing, which is suitable for the group mobility model in MANET. It uses the LGD-like stateless overlay multicast as the upper layer multicast protocol, and the counter-based 1-hop virtual flooding as the lower layer multicast protocol.

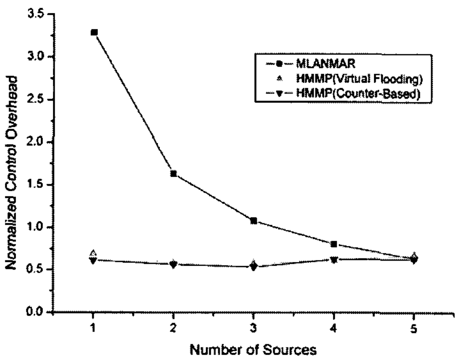

Fig. 5. Normalized Control Overhead (speed = 5m/s)

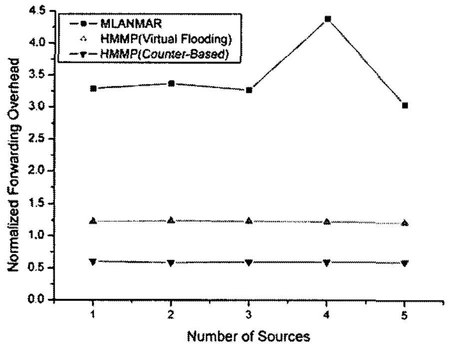

Fig. 6. Normalized Forwarding Overhead (speed = 5m/s)

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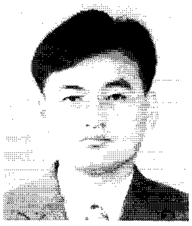
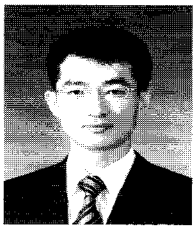


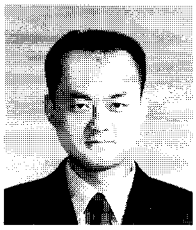
Kap-Dong Kim

Kim received BS and MS degrees in Computer Science from Chungnam National University, Korea, in 1998 and 2000, respectively. He joined ETRI, Daejeon, Korea in 2000. He worked on the development of the IMT-2000 system, Parlay and JAIN. From 2002 to 2006, he was involved in the development of the Next-Generation Internet Server. Since 2003, he has been working toward a PhD degree in Computer Science at ChungNam National University, Korea. Since 2007, he has been a senior researcher at the Agency for Defense Development. His research interests include high-speed networks architecture, quality of service in Internet and optical subscriber networks, MANET, multicast, network management, and Parlay.



Kwangil Lee

Lee received BS, MS and Ph. D degrees from the Dept. of Computer Science at Chungnam National University in 1993, 1996 and 2001 respectively. From 2000 to 2002, he worked as a guest researcher at the National Institute of Standards and Technology (NIST), USA. Then, he worked as a research associate at the University of Maryland (2002/2004) and the University of Texas (2005), USA. Since 2006, he has been a senior researcher with the Ubiquitous Home Middleware Team at the Electronics and Telecommunication Research Institute, Korea. His research interests include home networks, QoS, traffic engineering, routing, multicasting, power-line communication, wireless networks, MANET, and mobile IP.



Jun-Hee Park

Park received BS, MS, and Ph.D degrees in Computer Science from Chungnam National University, Korea, in 1995, 1997 and 2005, respectively. He joined ETRI, Daejeon, Korea in 1997. He was involved in the development of a work station clustering system from 1997 to 2000. He is currently participating in the development of an interoperable home network middleware framework. His current areas of interest are home network middleware, ubiquitous home services, and ad hoc networks. He is a member of the IEEE.

Sang-Ha Kim

Kim received a BS degree from Seoul National University, Seoul, Korea, in 1980, as well as an MS in Chemical Physics and a PhD in Computer Science from the University of Houston, Houston, USA in 1984 and 1989, respectively. He joined the System Engineering Research Institute (SERI) in the Korean Institute of Science and Technology (KIST), Seoul, Korea, as a Senior Research Scientist in 1990. After two years, he moved to Chungnam National University, where he is currently working as a professor. His current research concerns embrace all aspects of performance analysis, protocols, architectures, and implementation relating to all types of network, including the Internet and telecommunication networks. He has a special interest in the quality of services (QoS) in wired/wireless networks.