Dynamic Network Topology Configuration and Resource Switching for Real-Time Group Communication in a Ubiquitous Networking Environment

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ABSTRACT

In a ubiquitous networking environment, each user has diverse resources in terms of nodes, links and applications, so we proposed a resource switching mechanism to mediate the diversity between a pair of users. However, in group communication, the network topology of the group should also be taken into account. This is because a conventional approach using a server centric topology has a scalability problem on the server. Another mechanism using a peer-to-peer topology requires higher computation power and link bandwidth to the nodes for exchanging media data. Moreover, the available resources vary according to user context, and this affects the decision as to which topology to apply. In this paper, we propose a method to adapt our resource switching mechanism to real-time group communication. In order to avoid load concentration on the server and accommodate heterogeneous nodes, we introduce a novel network topology and a means of changing the network topology configurations dynamically. The experimental results using a prototype show that our system can reduce the load on the server and data delay.

Keywords: ubiquitous computing, mobile internetworking, group communication, sip, peer-to-peer

1 INTRODUCTION

There is a growing interest in real-time group communication services such as voice chat (e.g. PoC (Push to talk over Cellular)) [1] using cellular phones and video conferencing using stationary PCs. In the future, when a ubiquitous networking environment becomes a reality, it is expected that user resources in terms of the user nodes participating in the group, and links and applications on the nodes will become more diversified. In such an environment, application service providers (ASPs) should offer group communication services to users regardless of the differences in their resources. Additionally, suitable resources change according to the user's context, thus the services should be able to adapt the change without any disruption of the group communication.

Figure 1 depicts a user case scenario in the proposed system. (i) At first, Alice, Bob, Carol and Ted are enjoying video conferencing using their PCs. (ii) During the video conferencing, Alice must go out. As she wants to continue the conversation with them, she tries to switch the communicating node from her PC to her cellular phone. However, the cellular phone cannot handle video conferencing due to the limited data-processing capacity and communication bandwidth. Therefore, Alice's communication modality is switched from video conferencing to an audio conferencing. (iii) Meanwhile, video conferencing is continued between Bob, Carol, and Ted because their PCs have high processing performance and broadband connections.

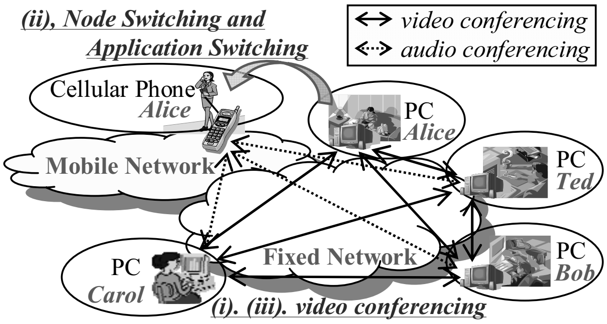


Figure1: User case scenario

The purpose of this paper is to construct a system that can realize this user case scenario in a ubiquitous networking environment. The existing systems cannot simultaneously resolve the issues involved, which are as follows.

We have proposed a mechanism that dynamically switches resources such as nodes, links and applications to prevent the termination of the communication caused by the changing situation (e.g. a user's physical movement) in person-to-person communication [2]. (1) However, in group communication, [2] is not sufficient because it takes into account only the resource switching between a requesting node and a requested node and not the other members' nodes, and it may result in the isolation of the group. (2) In addition to resource switching, the network topology of the group should be well considered. A conventional topology using a conference server to mediate the diversity of the resources in the group has a scalability issue at the server. Another mechanism using a peer-to-peer topology requires higher computation power and link bandwidth to the nodes for exchanging media data. (3) Moreover, the available resources vary according to user context and resource switching, thus it affects the decision as to which optimal topology to apply.

In this paper, we propose a system for real-time group communication that resolves the above-mentioned issues. To resolve issue (1), we propose a dynamic resource switching mechanism that can support not only person-to-person communication but also group communication. To resolve issue (2), we propose a novel network topology for data flow which employs user nodes with high processing performance as super nodes for accommodating low capability nodes instead of a conference server. For issue (3), we propose a dynamic network topology configuration mechanism that can dynamically switch the network topology according to the organization of nodes and links in the group.

The remainder of this paper is organized as follows. In Section 2, we first explain some issues of existing technology. In Section 3, we describe requirements for real-time group communication in a ubiquitous networking environment. In Section 4, we present a resource switching mechanism and dynamic network topology configuration to fulfill the requirements. In Section 5, we present the implementation of our prototype and a performance evaluation. In Section 6, we describe related work. Finally, in Section 7, we provide concluding observations.

2 EXISTING APPROACHES AND ISSUES

2.1 Resource Switching

We have proposed a resource switching mechanism for a pair of users to continue person-to-person communication services even if the user's situation changes [2]. In the case of [2], the origination node of a resource switching request switches the resources in terms of nodes, links and applications, and establishes new sessions with the termination node of the request.

When we apply this mechanism to group communication, it gives rise to the following issues. At first, all the nodes in the group except for the origination node become termination nodes. Therefore, multiple termination nodes should handle the resource switching request. For instance, in node and link switching, new sessions have to be established between all the termination nodes and the requesting node or link.

Moreover, in application switching, the termination nodes have to establish new sessions not only with the origination nodes but also among the other termination nodes to utilize the requested application among the group members. However, it should be noted that the necessity of this procedure depends on whether or not the same kinds of sessions with the requested application have already been established by other ongoing applications. For example, in case of application switching from video conferencing

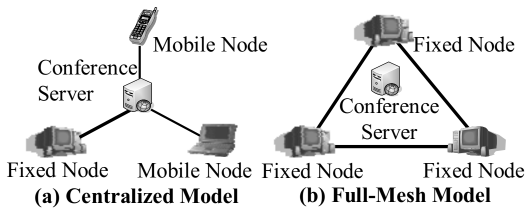


Figure2: Existing Network Topologies

to audio conferencing, new sessions do not need to be established among the origination node and termination nodes and among the termination nodes, because audio sessions have already been established by the current video conferencing. On the other hand, in case of application switching from audio conferencing to text chat, the origination node and termination nodes have to establish new sessions for text chat among them, because text message sessions have not been established by any ongoing application.

2.2 Network Topology Configuration

In group communication, not only the heterogeneity of the resources but the network topology organized by the participants should be taken into account. The reason is as follows. The existing network topologies of the data flow in group communication services may be typically classified into the following two models.

(1) Centralized Model

In order to implement a group communication service among different type of nodes, such as PCs with broadband connections and cellular phones with a low-speed connection, it is a typical solution to introduce a conference server to accommodate such heterogeneous nodes with codec conversion and/or data aggregation at the server (Figure 2(a)). This helps to provide the media data at an acceptable rate for the cellular phones. This topology configuration is called a centralized model.

In this model, it is possible to maintain communication between the heterogeneous nodes and reduce the load on each node better than in the full-mesh model as described below. However, there are some issues regarding the server, such as load concentration on the server and its access network caused by the increase in the number of accommodating nodes, and the Single Point of Failure (SPoF) problem. In addition, there is also an issue of increasing data delay between the nodes because the data flow goes through a redundant route via the server.

(2) Full-mesh Model

When all participants can use high performance nodes with broadband connections, it is possible to make each node communicate with each other directly (Figure 2(b)). This topology configuration is typically called the full-mesh model.

This full-mesh model can reduce the data delay compared with the centralized model, and prevent the SPoF issue. However, with the node and link switching described in Section 2.1, this model may cause termination of service. In case of a group utilizing the full-mesh model, a user who switches the node to a mobile node cannot continue the service any more, because the mobile node does not have enough performance to communicate with the other nodes in the full-mesh topology.

3 REQUIREMENTS FOR REAL-TIME GROUP COMMUNICATION SERVICES

We must consider the following requirements to resolve the issues mentioned in Section 2 in order to realize real-time group communication service in a ubiquitous networking environment which accommodates a great number of heterogeneous nodes.

Requirement 1: To provide group communication services continuously even if the user's situation changes, the system must support dynamic resource switching for group communication services.

Requirement 2: The system must organize a new network topology configuration for group communication to avoid load concentration on the server and simultaneously accommodate the heterogeneous nodes regardless of their capability.

Requirement 3: The system must adapt the topology configuration in group communication dynamically according to the organization of nodes in the group as a result of resource switching.

4 RESOURCE SWITCHING AND DYNAMIC NETWORK TOPOLOGY CONFIGURATION

4.1 Basic Features

In this section, we propose basic features to satisfy the three requirements described in Section 3.

Resource Switching for Group Communication

To satisfy Requirement 1 in Section 3, we extend our dynamic resource switching mechanism as follows.

At first, the resource switching request must be transferred to all nodes in the group. In order to achieve this, the origination node of the resource switching sends the request message to a conference server which manages the destination addresses of all participating nodes. The conference server then distributes the message to all the other nodes in the group.

Next, we must extend our application switching mechanism to allow the origination node and all the termination nodes to establish new sessions of the requested application among them to maintain the group communication in the application. For this purpose, the conference server is extended to determine whether new sessions for the requested application have to be established by comparing the kind of media data in the requested application and that in the existing session among the nodes. If the same kind of media is not covered in any existing sessions, a new session for the media must be established, so the conference server requests each node in the group to establish new sessions with all the other nodes. If the same kind of media is already covered, the conference server does not take any action regarding the media.

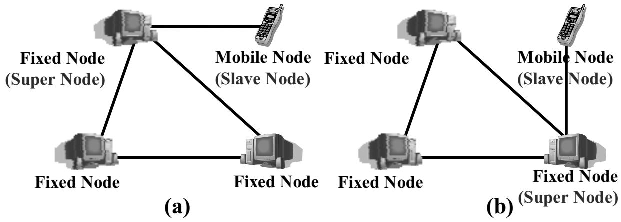


Figure3: Network Topology of Hybrid Model

Table1: Characteristics of Network Topologies

	Centralized	Full-Mesh	Hybrid
Server load	High	Low	Fair
Client load	Low	High	Fair
Supported Node	Mobile and Fixed Node	Fixed Node Only	Mobile and Fixed Node

Network Topology of Hybrid Model

The system must realize group communication among heterogeneous nodes and reduce the data processing load on the conference server and its access network to satisfy Requirement 2. We therefore propose a hybrid model as a novel network topology, which is shown in Figure 3(a) and (b).

To communicate with other nodes by using a mobile node, the system must have the same functions as the conference server in the centralized model, such as codec conversion and data aggregation, to compensate for the poor computation capability and the low-speed link of the mobile node. However, in the centralized model, there are some issues such as load concentration etc. Therefore, in the hybrid model, we extend the full-mesh model to apply some participant nodes that have a high computation power and a broadband link to accommodate a mobile node instead of the conference server so as to avoid the concentration of processing load. The mobile node then communicates with other nodes via one of these nodes. As shown in Figure 3, we define a node accommodates other nodes as a super node and a node accommodated by the super node as a slave node.

However, data transmission still may become difficult if the processing load on the super node and the traffic on its link increase due to the increase in the number of the slave nodes. Therefore, this mechanism can also reduce the load on the high loaded super node by assigning the accommodated slave nodes to other low loaded super nodes as shown in Figure 3 (b).

Table 1 summarizes the main characteristics of the three topologies: the centralized model, the full-mesh model and the proposed hybrid model. By using the hybrid model, the load on the conference server (server load) can be reduced compared with the centralized model, because some super nodes accommodate the slave nodes instead of the conference server. Additionally, by introducing the super node, the load on the slave nodes and its links (client load) can be reduced compared with the full-mesh model.

Dynamic Network Topology Configuration

In a ubiquitous networking environment, as shown in Table 1, the optimal topology is different according to the organization of nodes in a group.

Additionally, because node and link switching in group communication may affect the organization of the nodes, the optimal network topology configuration is changed dynamically.

To provide the optimal topology for ongoing group organization, we propose a dynamic network topology configuration mechanism that can dynamically switch the topology in a group according to the number of super nodes and slave nodes. For example, when all nodes become slave nodes, the topology is switched to the centralized model because it is the only possible topology. If all the slave nodes leave the group, the topology is switched to the full-mesh model because all nodes can communicate each other directly. If there are both slave nodes and super nodes in the group, the topology is switched to the hybrid model as described in the above.

4.2 System Architecture

Figure 4 shows a system architecture that is composed of Client Nodes, a Session Management Server and a Conference Server. The Session Management Server is a server with the above-mentioned conference server's functions which manages sessions between each Client Node and orders resource switching between each one. The Conference Server in Figure 4 is a server with the above-mentioned conference server's function except the function of session management.

Client Node

The client node executes applications for real-time communication such as video conferencing or audio conferencing etc. It is a SIP UE (User Equipment), which comprises a Service Manager, State Monitoring Manager, Network Manager, Data Transfer and GUI Controller modules.

The Service Manager manages sessions to register oneself, to attend or leave group communication service and to invite other nodes. It also manages sessions to

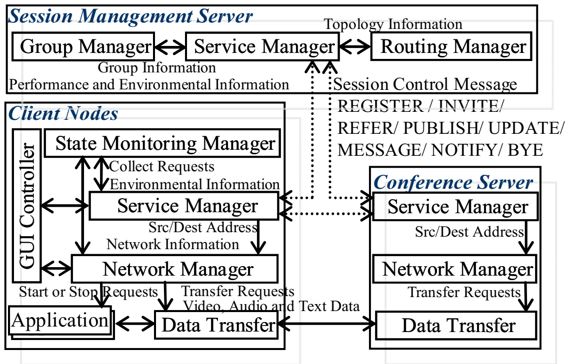


Figure4: System Architecture

request resource switching. The State Monitoring Manager manages CPU and memory utilization, maximum link speed and data delay between other nodes, and then notifies them to the Session Management Server through the Service Manager. The Application sends or receives the media data through the Data Transfer Module. The Network Manager manages the Application and requests transmission of the media data to the Data Transfer module. If a node is super node capable, it also manages sending and receiving the media data for the slave nodes. The Data Transfer module sends and receives the media data by request from the Network Manager. The GUI Controller receives user operations, and sends them to the Service Manager Module and Network Manager Module.

Session Management Server

The Session Management Server manages group and user identifications, registers and deregisters Client Nodes and collects and manages session information in the group. It is a SIP AS (Application Server), which comprises a Service Manager, Routing Manager and Group Manager. The Service Manager manages the sessions of each Client Node and Conference Server, and relays resource switching requests from a node to others. It also monitors the state provided by the State Monitoring Manager in the Client Nodes. The Routing Manager has a dynamic topology configuration function. The Group Manager manages the groups organized by several Client Nodes.

Conference Server

The Conference Server processes the data flow from the slave nodes, and accommodates them when any super node does not exist in a group or cannot accommodate a slave node any more. It is a SIP AS, which comprises a Service Manager, Network Manager and Data Transfer module. Each module of the Conference Server works like imitating a super node.

4.3 Resource Switching Mechanism

We explain the resource switching mechanism with an example of resource switching (Figure 5 on next page) based on the user case scenario in Figure1.

(i) Video conferencing

Sessions for video conferencing are established between each pair of fixed nodes (TE a1 of Alice, TE b1 of Bob, TE c1 of Carol and TE d1 of Ted). In this situation, Alice switches using node from a fixed node (TE a1) to a mobile node (TE a2), and the application from video conferencing to audio conferencing.

(ii) Node and application switching

To switch these resources, TE a2 sends a resource switching request message that includes the address of TE a1 in the header part and the type of media data (audio in this case) in the body part to the Session Management Server by using the REFER method (Figure 5 (1)). The Session Management Server sends TE a1 a response message (Figure 5 (2)), and then sends TE a1 request message to stop video conferencing for switching the user node of Alice to TE a2 and sends TE a2 a message to notify start of the resource switching. (Figure 5 (3)-(4)). If the Session Management Server receives 200 OK from TE a1, it must call the Routing Manager module for the network topology configuration described below because the type of node used by Alice changes.

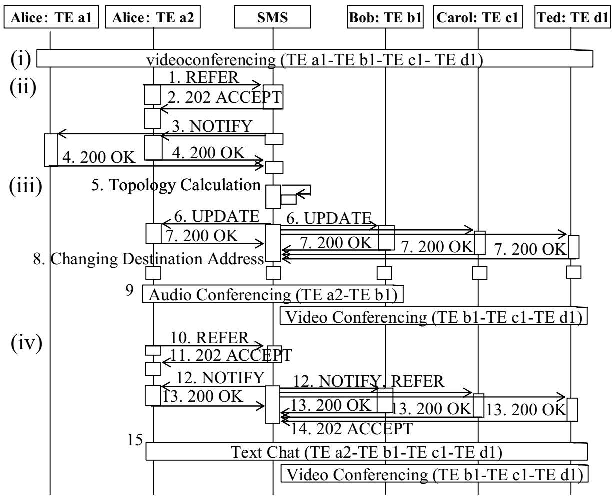
(iii) Network topology configuration

After the Session Management Server calls the Routing Manager module, it calculates the optimal topology (Figure 5 (5)) for the current group organization. In this scenario, TE a2 is determined to be a slave node when it registers with the Session Management Server because of its low performance and narrow link. In addition, the server determines all the fixed nodes to be super nodes. As a result, it is determined to change the topology from the full-mesh model to the hybrid model because the group is composed of one slave node and four super nodes and TE b1 is assigned as a super node for TE a2. These decisions are explained in 4.4 and 4.5 in more detail. The server then sends request messages to change the destination address for the data flow to TE a2, TE b1, TE c1 and TE d1 by using the UPDATE method (Figure 5 (6)-(7)). By these requests, TE a2 sets the destination address to TE b1, TE b1 changes the destination address of TE a1 to TE a2, and TE c1 and TE d1 change the destination address of TE a1 to TE b1 (super node) (Figure 5 (8)).

As a result of the above switching, among TE a2, TE b1, TE c1 and TE d1, audio conferencing begins in the hybrid topology. The slave node TE a2 is accommodated by the super node TE b1. On the other hand, among TE b1, TE c1 and TE d1, the topology maintains the full-mesh model and they continue video conferencing (Figure 5 (9).

(iv) Application switching involving the establishment of new sessions among the nodes

We would like to explain an alternative case where the requested application has an unused type of data flow such as text chat. In this case, the Session Management Server needs to establish new sessions between each node. At first, the origination node, TE a2, requests application switching



SMS: Session Management Server

Figure5: Sequence in Resource Switching

for text chat in the same way as (ii) to the Session Management Server (Figure5 (10)-(11)). The Session Management Server then requests application switching to TE a2, TE b1, TE c1 and TE d1 by using the NOTIFY method. In this case, because the text chat has a new type of data flow, text streaming, the Session Management Server requests TE b1, TE c1 and TE d1 to setup new sessions of text streaming for each other by using the REFER method (Figure 5 (12)-(14)). Therefore, text chat sessions are established between all pairs of TE a2, TE b1, TE c1 and TE d1 (Figure 5 (15)).

4.4 Hybrid Network Topology Configuration Mechanism

This mechanism configures the hybrid model by managing the Client Nodes and their links at the Session Management Server. The details are shown as follows.

1. Client nodes and network management

The Session Management Server collects performance information such as CPU performance, memory capacity and maximum speed on the link to divide Client Nodes into slave nodes, super nodes and others.

At first, the Client Node registers itself with the Session Management Server by using the REGISTER method. After the completion of registration, it sends the performance information by using the PUBLISH method.

Next, each Client Node periodically sends environmental information such as CPU utilization, memory utilization and data delay. To measure data delay, each node sends a message to other nodes by using the MESSAGE method. However, Client Nodes which are determined to be slave nodes do not perform the measurement of environmental information to avoid increasing the load on the node and the link.

Sl =0 (Full-Mesh) --- (1)

Sl≧1:
- Sn =0:
  - N-Sl≧2 (Hybrid using CS) --- (2)
  - N-Sl≦1 (Centralized) --- (3)
- Sn≧1:
  - N≧3 (Hybrid) --- (4)
  - N=2 (Full-Mesh) --- (5)

Sn: Super Node
Sl : Slave Node
N : Number of nodes
CS: Conference Server

Figure6: Conditional Expression

2. Division into slave nodes and super nodes

The Session Management Server divides Client Nodes into slave nodes and super nodes according to performance information and environmental information collected from each Client Node. At first, when a value in the performance information of a Client Node is below a threshold (slave node threshold) that is set by the system operator beforehand, the Session Management Server determines that the node is a slave node. On the other hand, when all values of the performance information of a Client Node exceed another threshold (super node threshold), the Session Management Server determines that the node is a super node. It is possible that a Client Node is determined neither a super node nor a slave node. This implies that this kind of node can organize the full-mesh topology but cannot accommodate any slave nodes.

3. Assignment of slave nodes to super nodes

Next, the Session Management Server makes a list of the super nodes in order of highest value of environmental information, and preferentially assigns the slave nodes to a super node that is in a higher rank of this list.

4. Load distribution of super nodes

Increasing the number of slave nodes connected to a super node gives rise to much more media data and processing load on the super node. To avoid the concentration of load, the Session Management Server refers to each parameter of the latest environmental information and recreates the list of super nodes. From the list, it reassigns the slave nodes to other more lightly loaded super nodes or a new super node. After the reassignment, the Session Management Server requests to change the destination of the session to the reassigned node. Further, when the load on all super nodes is increased or there is no super node in the group, this mechanism also allows a group communication to use the Conference Server as a new super node.

4.5 Dynamic Network Topology Configuration Mechanism

This mechanism dynamically configures network topology among the centralized model, the full-mesh model and the hybrid model according to the number of super nodes and slave nodes.

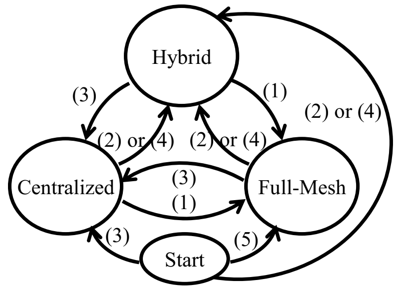


Figure7: State Transition Diagram

1. Determination of topology

Figure 6 shows conditional expressions to determine the optimal topologies. When there are no slave nodes in a group, the topology becomes the full-mesh model (Figure 6(1)). On the other hand, when one or more slave nodes exist, there is no super node and the number of Client Nodes excluding slave nodes is more than two (which means there are one or more clients that are neither slave nodes nor super nodes), the topology becomes the hybrid model using the Conference Server as a super node for the slave nodes (Figure 6(2)). When the number of client nodes excluding the slave nodes is less than one, the topology becomes the centralized model (Figure 6(3)).

In the case where there are one or more slave nodes and one or more super nodes and if the total number of all the Client Nodes is greater or equal to three, the topology becomes the hybrid model (Figure 6(4)), otherwise the topology becomes the full-mesh model because the number of the all Client Nodes is two (Figure 6(5)).

2. Topology switching

As mentioned above, when the optimal topology changes, the Session Management Server sends topology switching requests with new destination addresses of the data flows to the client nodes whose destination addresses should be changed in the new topology. The requests are sent by the UPDATE method.

The client nodes that receive the request change the destination address to the requested one. The state transition diagram of the topology switching is shown in Figure 7. The numbers in parentheses Figure 7 correspond to the number of the condition expression in Figure 6.

5 EXPERIMENTS AND EVALUATION

5.1 Experiments

Figure 8 on next page shows the experimental testbed setup. Five nodes can participate in a group communication. TE a1, TE b1, TE c1 and TE d1 are fixed nodes which connect to a fixed network (100BASE-TX) separated by Router B and Router C. The Session Management Server and Conference Server connect to another fixed network

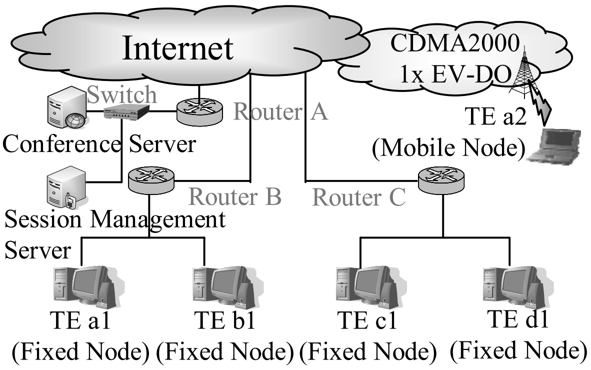
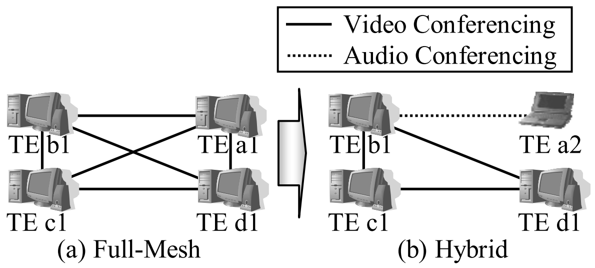


Figure8: Experimental Testbed Setup



Figre9: Experimental Setup for Resource Switching and Dynamic Network Topology Configuration

(100BASE-TX) through Router A. TE a2 is a mobile node which connects to the cellular network (1x EV-DO). All the fixed nodes and the servers are stationary PCs with a 2GHz CPU and 1Gbyte memory. The mobile node is a laptop PC with a 1.3GHz CPU and 256Mbyte memory. Each router connects to the Internet through an 8M ADSL network. In this testbed, the following two experiments were performed to evaluate the proposed system performance.

1 Resource Switching and Dynamic Network Topology Configuration

The purpose of this experiment is to evaluate continuity of group communication services during resource switching and the dynamic network topology configuration. In this experiment, the user's resources are switched according to the scenario shown in Figure 1. The sequence of this experiment is shown in Figure 5 and its topology is shown in Figure 9. Stimulated by the node switching, topology switching from the full-mesh model (Figure 9 (a)) to the hybrid model (Figure 9 (b)) is also performed. In this environment, we measured the following items to confirm these processes do not lead to termination of the entire communication service.

(i) Node and application switching time: t1

This is the time from sending a REFER message to request node switching at TE a2 to the arrival of audio data from other nodes at TE a2 (Figure 5 (1)-(9)).

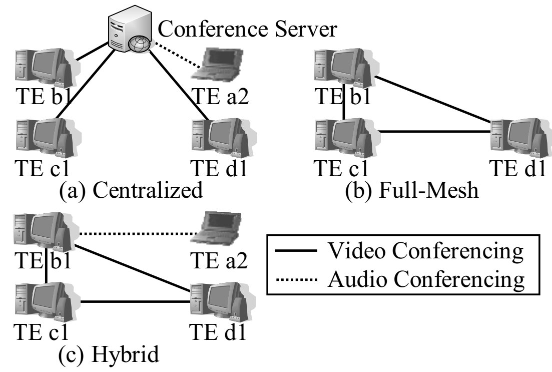


Figure10: Comparisons of Network Topologies

(ii) Data stream interruption time: t2

This is the time from stopping receiving the video and audio data stream for video conferencing at TE a1, to the beginning of receiving the audio data stream for audio conferencing at TE a2 (Figure 5 (8)-(9)). It is equal to the service disruption time for the user.

(iii) Destination Address Switching Time: t3

This is the time from sending an UPDATE message at the Session Management Server to the completion of changing the destination address at each node (Figure 5 (6)-(8)).

2 Comparisons of Network Topologies

The purpose of this experiment is to evaluate the hybrid model in terms of delay reduction between heterogeneous nodes and load reduction on the Conference Server and each node by comparing with the other models. Figure 10 shows the network topologies used in this experimentation. Figure 10(a) shows the centralized model where all the media data is sent and received through the Conference Server. Figure 10(b) shows the full-mesh model where each node sends and receives media data directly without using the Conference Server. Figure 10(c) shows the hybrid model. The super node TE b1 accommodates the slave node TE a2.

In each topology, all the fixed nodes are able to perform video conferencing, but the mobile node is able to use only audio conferencing. In addition, TE a2 do not have enough link bandwidth to send and receive audio data with more than one node.

In this testbed, there is a difference in the communication delay of the fixed network section (Wired) and of the mobile network section (Unwired). Therefore, we classified the measurement area into Wired-Wired communication (between TE b1 and TE c1, TE c1 and TE d1, TE d1 and TE b1) and Wired-Unwired communication (between TE b1, TE c1, TE d1 and TE a2), and measured each data delay.

We also measured CPU and memory utilization on the Conference Server and each node for the centralized model and the hybrid model to evaluate the load reduction feature of the hybrid model.

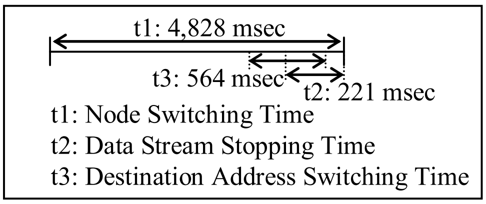


Figure11: Times for Resource Switching and Dynamic Network Topology Configuration

5.2 Experimental Results and Evaluation

The experimental results and the evaluation are as follows.

1. Measurement Result for Resource Switching and Dynamic Network Topology Configuration

Figure 11 shows the time series of the measured events for resource switching and dynamic network topology configuration. The result of t1 was about 4,828 [msec]. In t1, the time to exchange messages between a mobile node and a fixed node or the Conference Server via the cellular network (Figure5 (1)-(4) and (6)-(7)) was dominant and was about 2,667 [msec] in total. The result of t2 was 221 [msec]. This is because it not only takes time for routing and switching, but there is also the arrival time of packets which sent via the new route. The result of t3 was 564. Most of the time is required to send packets through the wireless area.

As a result, the time for processing the resource switching and dynamic network topology configuration (t1, t3) was relatively large, but the actual service disruption time (t2) was still kept at an acceptable level for the real-time communication applications in this environment.

Therefore, it can be said that our resource switching mechanism for group communication can provide service continuity (Requirement 1 described in Section 2.2). Moreover, it can also be said that our dynamic network topology configuration can adapt the topology configuration dynamically according to the utilized resources as a result of resource switching (Requirement 3 described in Section 2.2).

2. Comparison Result of Network Topologies

Figure 12 shows the frequency distribution of data delay as the result of data delay measurement for 180 seconds between each node in each topology. The horizontal axis indicates the data delay and the vertical axis is the frequency of data delay.

The graph roughly shows that the average delay and delay fluctuation of Wired-Unwired communication are much larger than those for Wired-Wired communication. This is because both the network delay and jitter in the mobile network are much larger than the fixed network. With regard to Wired-Wired communication, the full-mesh model and the hybrid model show the same average of 30 [ms] because the topology configurations for stationary PCs are completely identical. On the other hand, in the centralized model, the average value is about 100 [ms]. This is caused by the extra route in which all the data flows transit the Conference Server. With regard to Wired-Unwired communication, the delays of the hybrid model and the centralized model are mostly about 100 - 400 [ms] and 370 - 700 [ms]. The data delay in the hybrid model is smaller than in the centralized. This is because the data flow among TE b1, TE c1 and TE d2 in the hybrid model is not routed via the Conference Server, and is sent or received directly. Moreover, media data sent from TE a2 to TE c1 and TE d1 are routed via TE b1, but TEb1 and TE c1 are in the same segment, and TE b1 and TE d1 are in the same provider's network.

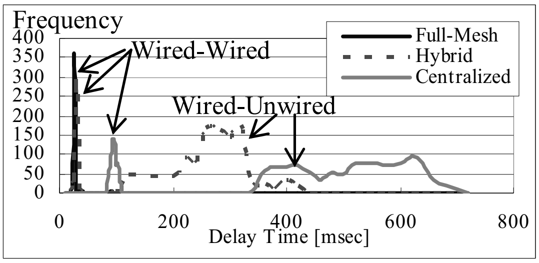


Figure12: Frequency Distribution chart of Data Delay in Each Topology

Table2: CPU and Memory Utilization in Centralized and Hybrid Topology

	CPU Utilization			Memory Utilization		
	S	F	M	S	F	M
Centralized	0.7	3.4	2.7	93	26	94
Hybrid	2.4	3.7	2.7	35	30	94

S: Conference Server (Centralized) or Super Node (Hybrid)
F: Fixed Node but not Super Node
M: Mobile Node

Table2 shows the result for the CPU and memory utilization of the Conference Server and each node. The unit of all values is percent. In the centralized model, CPU utilization and memory utilization of the Conference Server for the group communication service were 0.7 % and 93 % on average. The measurement results for CPU utilization of fixed nodes and mobile nodes were 3.4 % and 2.7% on average, and their memory utilization was 26% and 94% on average.

On the other hand, in the hybrid model, CPU utilization in a super node, a slave node and other fixed nodes was 2.4% 2.7% and 3.7%, and memory utilization was 35%, 94% and 30% on average.

From the measurement results for CPU utilization, all the values were relatively low, and there was practically no explicit difference in topologies except for the super node and the Conference Server because the PC used had enough CPU performance to execute the application. The increase of CPU utilization in the super node was due to the additional process of the Data Transfer Module in forwarding media data from or to TE a2. From the measurement results for memory utilization, utilization at the server was rapidly reduced because the data flows were distributed to each node except for the stream between the super node and the slave in the hybrid model. In order to forward the data flow to the slave node, the utilization of the super node is slightly increased compared to the other fixed nodes.

Therefore, it can be concluded that memory utilization of the Conference Server in the centralized model was reduced by distributing the process to each node in the hybrid model (Requirement 2 described in Section 2.2).

6 RELATED WORK

This framework has previously been examined for group communication. For example, in IETF (Internet Engineering Task Force), the framework using SIP [3] has been examined [4] [5]. The centralized model is mainly described in IETF and other organizations because these frameworks can provide users with a stable environment [6] [7]. The full-mesh model is also attracting attention due to the ease of configuration of the system from the nature of the architecture [8]-[11]. For example, in IETF, an architecture called P2P-SIP is proposed and discussed. These frameworks have the issues described in Chapter 3. However, comparing with the centralized model, our hybrid model can distribute the load on the server. Additionally, comparing with the full-mesh model, it can accommodate heterogeneous nodes from the results of the experiments described in Section 5.2.

In related studies on resource switching, a host mobility mechanism has been proposed [12]. For instance, by using a mobile IP [13], users can maintain communication with each other even if they switch the link on the node. However, in these proposals, it is difficult to switch the node or application. On the other hand, our resource switching mechanism supports these kinds of switching as proved by the results of the experiments in Chapter 5.

7 CONCLUSION

In this paper, we proposed a method to adapt our resource switching mechanism to realize real-time group communication in a ubiquitous networking environment. Moreover, to avoid the load concentration on the server and accommodate heterogeneous nodes regardless of their capability, we introduced a novel network topology for group communication and a means of changing network topology configurations dynamically based on user situations.

We implemented a prototype based on the proposal and measured the performance. As a result, we confirmed that the proposed system can switch communication resources while maintaining the group communication, and reduce load concentration on the server.

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