Challenges and Solutions for Routing in Converged Satellite and Terrestrial Networks

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Abstract—A converged satellite and terrestrial network (CSTN) can be used for globally unified networking in areas where there is no infrastructure. However, the different characteristics between a satellite network and a terrestrial network lead to researches on converged network architectures, data transmission methods, resource managements, and etc. In this paper, we deal with these research issues in terms of efficient routing of user data and the employment of routing protocols in the CSTNs. First, we suggest a network architecture for the selection of efficient routing path based on several design criteria. Then, we figure out issues and their solutions when a dynamic routing protocol is applied to the CSTNs. These issues are focused on the signaling process for connection setup and maintenance, resource allocation for a satellite link, and mobility management. We have shown that the CSTNs can achieve the efficient routing path selection, increase channel utilization, and decrease signaling overheads for the exchange of routing information by using the suggested solutions.

Keywords—converged network, satellite network, terrestrial network, routing

I. INTRODUCTION

In a tactical area, the absence of infrastructure may occur more frequently because of enemies’ attacks. This damage can be critical to military operations. For example, it may result in the difficulty in the situational awareness of a commander, resulting in the difficulty to quickly and appropriately decide on commands from a command center. Thus, the fast deployment of a network infrastructure is one of key factors to improve the performance ability of military operations. However, most wireless communication systems require a lot of time and efforts to recover a destroyed network. Moreover, a soldier can sometimes move into areas where there is no infrastructure. For this reason, most conventional terrestrial communication systems are not suitable for military communication.

In a tactical communication network, it is important to rapidly configure a communication network. A satellite communication is a key technology that can help to communicate in shadow areas where there is no infrastructure. Generally, it can provide a communication link to a soldier immediately because a satellite communication is not limited to geographical features.

In recent researches, the CSTNs have been noted as a technology to overcome limitations of terrestrial networks [1]. Especially, Korean military has considered the CSTNs as an alternative to improve the operation performance ability. In this regard, it may be expected that the satellite systems for the next generation can be interworked with terrestrial networks. In the literature, there have been several key issues to integrate satellite networks and terrestrial networks; e.g., design of a network architecture, employment of routing protocol, resource allocation method, and mobility management. To efficiently make use of the CSTNs, these issues should be considered simultaneously.

In this paper, we deal with research issues such as efficient routing of user data and the employment of routing protocols in the CSTNs. We first suggest a network architecture for the selection of efficient routing paths based on several design criteria. Then, we deal with some issues related to the signaling process of dynamic routing protocols, resource allocation, and mobility management before finding their solutions. The solutions include the exchange procedure of control messages in a dynamic routing protocol and the suggestion of three kinds of resource allocation methods for the transmission of control messages. We also suggest a method for updating routing tables and the IP address allocation policy to support mobility. The suggested solutions can contributed to the employment of the CSTNs for tactical networks in terms of the following four aspects.

- Network architecture design for the CSTNs
- Modification of dynamic routing protocol for satellite
- Increase in channel utilization over satellite link
- Decrease in control overheads for dynamic routing

The remainder of this paper is organized as follows. In the next section, we introduce a CSTN in the developed world. In section III, we will discuss the management of routing information and the network architecture for efficient routing in the CSTN. Thereafter, in section IV, the issues and their solutions for the employment of routing protocol are described in terms of four aspects; i.e., exchange procedure of
control messages, the modification of dynamic routing for a satellite link, and mobility management. Finally, conclusions are drawn in section V.

II. RELATED WORKS

This section introduces conventional studies related to the CSTNs. Recently, a few systems have been introduced for the CSTNs. The digital video broadcasting by satellite (DVB-S) and the digital video broadcasting return channel satellite (DVB-RCS) have been proposed by European telecommunications standards Institute (ETSI) [2], [3]. DVB-S and DVB-RCS systems provide digital television broadcasting services and interactive broadband communications. Fig. 1 depicts the DVB-S/RCS system with onboard switching [4]. The return channel satellite terminal (RCST) will be configured with the IP network addresses corresponding to active local area network (LAN) interfaces. An RCST offers an Ethernet interface to users that can be used for interactive internet protocol (IP) connectivity. IP terrestrial networks are connected to DVB-RCS networks through gateway stations. Thus, a user can use interactive broadband service as well as multimedia broadcasting services. In DVB-RCS systems, the RSCT supports static routing and may optionally support dynamic routing [3].

In CISCO, satellite radio area network (SatRAN) has been proposed for converged ground-to-space network architecture [5]. SatRAN connects end users to terrestrial IP networks through a satellite. In SatRAN, a satellite mounting a space routing as well as a bent-pipe satellite are considered. To test the possibility of the space router, CISCO launched the first commercial router in geostationary orbit at 2009.

In the DVB-S/RCS systems, almost user terminals may not move into other areas. However, in the tactical networks, network elements such as user terminals and access points can move around the operation areas. Thus, a network topology may be dynamically changed and the routing tables should reflect information on the changed network topology. Therefore, dynamic routing algorithms should be applied to tactical networks. Moreover, SatRAN has focused on the network architecture design, but SatRAN does not take into account dynamic routing protocol and the resource allocation of satellite links. Consequently, the routing protocols and the network architecture for DVB-S/RCS systems and SatRAN are unsuitable for efficient routing in the CSTNs. In this paper, we figure out some issues and their solutions when designing and employing a dynamic routing protocol.

III. NETWORK ARCHITECTURE

For efficient routing, it is important to design a network architecture. Especially, the management structure for routing information and the functions of network entities have a direct influence on network performances, which are related to data transmission, such as control overhead and optimal routing path. In this section, we discuss the network architecture for efficient routing in the CSTNs.

A. Management Structure of Routing Information

In Korea, next generation satellite networks have been considered as hierarchical and distributed networks. Fig. 2 depicts the reference network architecture of the CSTNs. A network control center (NCC) and hubs perform the connection control and resource allocation on the overall networks and distributed networks, respectively. In the future tactical networks, satellite networks can be interworked with existing terrestrial tactical networks. To transfer data of a user who belongs to terrestrial networks, an NCC and hubs must have routing information corresponding to terrestrial networks. Thus, the issue related to the management of routing information is important for the efficient operation of routing protocol because the amount of control overheads for the exchange of routing information can be changed according to the management structure of routing information. In this paper, we consider two methods related to the management structure of routing information. First, an NCC and hubs collect routing information related to
overall CSTNs. Second, an NCC or a hub collects routing information on its own distributed network only.

There is trade-off between two methods for the management of routing information. In the first method, a satellite terminal can directly transfer a packet to a satellite terminal which belongs to the neighbor’s distributed network. On the contrary, when using the second method, a satellite terminal selects a routing path which passes through an NCC or upper layer distributed network. Thus, the first method results in more efficient routing path between distributed networks. However, in the first method, the control messages for the exchange of routing information occur more frequently than the second method because a control center collects routing information on the overall networks.

In a military environment, traffics usually occur between terminals within the same tactical operation group. Therefore, if a distributed network is designed for tactical operation groups, the second method is more suitable for the tactical networks.

B. Design of Network Architecture

There are many network entities in the CSTNs. For efficient routing, it is important to define functions of network entities. However, in conventional satellite networks, networks entities such as an NCC and user terminals do not take into account IP routing. Thus, the functions related to routing should be defined in the CSTNs. In this subsection, we estimate the routing path according to the functions of network entities. For this purpose, we consider various routing scenarios. We introduce six criteria to design the routing scenarios, and consider all combinations of those criteria. Then, we assess advantages and disadvantages for each routing scenario and propose an efficient network architecture for the CSTNs.

1) Design Criteria of the Network Architecture: We consider six criteria as shown in Table I. The first criterion is autonomous system (AS) separation. We consider two scenarios. One is the location based AS and the other is device type based AS. In the location based AS, the devices in the same region compose an AS. In contrast, an AS is composed of only the satellite devices without the terrestrial devices even though they are in the same region. The second criterion is the NCC configuration. We propose that the NCC operates with the border gateway protocol (BGP) routers. The third criterion is the topology of satellite link. The satellite devices transmit a data packet using a star topology or a mesh topology. The fourth criterion is device configuration. We consider that a satellite device operates as an internal router (IR). The next criterion is the location of a source and a destination device. We consider two cases. The first case is that a source and a destination device are in the same AS. The other case is that they are in the different ASs. The last criterion is the type of a source and a destination device. The four cases for the last criterion are shown in Table I.

The total possible number of possible scenarios is 128. However, in this paper, we focus on the routing performance of the scenarios related to the functional feature of an NCC and a satellite terminal.

2) Network Architecture for Efficient Routing Path Selection: In this paper, we estimate the routing path the

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**Table I**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Categories</th>
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<tbody>
<tr>
<td>AS separation</td>
<td>Location based AS</td>
</tr>
<tr>
<td></td>
<td>Device type based AS</td>
</tr>
<tr>
<td>NCC configuration</td>
<td>NCC operates with BGP routers</td>
</tr>
<tr>
<td></td>
<td>NCC operates without BGP routers</td>
</tr>
<tr>
<td>Topology of satellite</td>
<td>Star/Mesh topology</td>
</tr>
<tr>
<td>Device configuration</td>
<td>Device operates with an IR</td>
</tr>
<tr>
<td></td>
<td>Device operates without an IR</td>
</tr>
<tr>
<td>Device configuration</td>
<td>Source and destination placed in same AS</td>
</tr>
<tr>
<td></td>
<td>Source and destination placed in different AS</td>
</tr>
<tr>
<td>Device type of source and</td>
<td>- 4 cases: (Source, Destination)</td>
</tr>
<tr>
<td>destination</td>
<td>(Terrestrial, Terrestrial), (Satellite, Satellite)</td>
</tr>
<tr>
<td></td>
<td>(Terrestrial, Satellite), (Satellite, Terrestrial)</td>
</tr>
</tbody>
</table>
following two cases.
- NCC configuration
- Satellite terminal configuration

We do not consider the other cases because the other cases are minor and had been treated in [6]. We first consider that the NCC operates with BGP routers. We estimate the routing paths based on the device types of a source and a destination device. Fig. 3 shows the difference of the routing paths between the scenarios for a NCC configuration. Fig. 3 (a) depicts a scenario where a source and a destination are satellite devices, \{Satellite, Satellite\}, and Fig. 3 (b) depicts another case, \{Satellite, Terrestrial\}. In Fig. 3, the solid lines and the dotted lines mean routing paths when the NCC operates without or with BGP routers, respectively. In case of \{Satellite, Satellite\}, a data packet must pass through the autonomous system boundary router (ASBR) to reach a destination device which belongs to another AS when the NCC operates without the BGP routers. On the other hand, the data packet is directly transferred to the destination when the NCC operates with BGP routers because the BGP routers operate as ASBR to all ASs in the network. Thus, when the NCC operates with BGP routers, the routing path is shorter compared with that of the case when the NCC operates without BGP routers. Therefore, end-to-end delay is reduced and the resource of satellite link can be used more efficiently. This happens more and more as the number of ASs between AS X and AS Y is increased because the data packet must pass through more ASBRs of the all ASs on the routing path.

We introduce the scenarios where the satellite devices operate as an IR. In this case, a satellite device can transmit and receive a data packet with terrestrial device. This can reduce the resource consumption of a satellite link. Also, a satellite device can operate as an intermediate node on the routing path. For example, when a terrestrial device transmits a data packet to a satellite device, the satellite device relays the data packet to a next hop device using the satellite link. However, the IP protocol of a satellite device should be modified to separate the relayed data packets from the received data packets. Also, the additional operational expenditure occurs.

Especially, a satellite device which is designed as IR can operate as a relay node. However, the cost for operation and maintenance of converged network is increased.

IV. DYNAMIC ROUTING PROTOCOL

In tactical networks, network elements have high mobility compared with DVB-S/RCS network elements. This can lead to the dynamic change of the network topology. Thus, a dynamic routing protocol should be applied to tactical networks. In this paper, we consider open shortest path first (OSPF) algorithm as a dynamic routing protocol. We find out issues and their solutions when OSPF algorithm is applied to the CSTNs. We focus on the issues in terms of three aspects; i.e., signaling process for connection setup and maintenance, modification of dynamic routing protocol for satellite links, and mobility management for satellite terminal.

A. Signaling Process for Connection Setup and Maintenance

In a dynamic routing protocol, the control messages for connection setup and maintenance occurs frequently. OSPF has five types of packets; i.e., Hello, data description packet (DDP), link state request (LSR), link state update (LSU), and link state acknowledgement (LSAck) [7]. OSPF uses the control packets for connection setup, connection maintenance, or the exchange of routing information. To apply OSPF to the CSTNs, the operational characteristics of satellite networks should be reflected in the OSPF algorithm. Fig. 4 depicts the exchange procedure of the OSPF packets between satellite terminals. A satellite terminal requests link connection and resource allocation to either an NCC or a hub whenever packets are generated because both the required resource for the generated traffic is only allocated to the satellite terminal and the satellite terminal releases the resource after completing the transmission of the generated traffics. For example, a satellite terminal requests resource by estimating the amount of OSPF packets for initial IP connection setup and releases the resource after completing the connection setup.

B. Modification of Dynamic Routing Protocol for Satellite Links

A packet experiences delay due to resource allocation and link propagation in the satellite networks. To prevent the wrong behavior of the OSPF, the delays should be reflected in the algorithm for the exchange of the OSPF packets. Especially, a Hello packet are periodically exchanged to maintain a routing path. When the Hello packet is received from a neighbor’s router within four transmission attempts,
Table II

<table>
<thead>
<tr>
<th>Environments</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propagation delay</td>
<td>125 msec (Terrestrial to satellite)</td>
</tr>
<tr>
<td>Time for resource allocation</td>
<td>Uniform distribution, mean = 2 seconds</td>
</tr>
<tr>
<td>Channel model</td>
<td>Additive white gaussian noise</td>
</tr>
<tr>
<td>Modulation</td>
<td>4-Quadrature amplitude modulation</td>
</tr>
<tr>
<td>Hello packet size and period</td>
<td>44 bytes, 10 seconds</td>
</tr>
</tbody>
</table>

Figure 5. Average transmission delay of a Hello packet

Figure 6. Mobility scenario of a satellite terminal

the OSPF maintains a routing path corresponding to the router [7]. If the algorithm for the exchange of the Hello packet does not take into account the delay, the router disconnects relationship with the neighbor’s router in spite of receiving the Hello packet because the transmission delay of the Hello packet can be increased according to traffic load. Therefore, the additional delay should be reflected to a timer for a Hello packet. Table II and Fig. 5 represent the environments for the performance evaluation and the average transmission delay of a Hello packet [7]. We assume that the time for resource allocation follows the uniform distribution whose mean value is 2 seconds. From the evaluation result, it is found that the average transmission delay can be increased by approximately up to 43 seconds due to the resource allocation and propagation delay. Thus, the router deletes the path from the routing table because the expiration time of the timer is 40 seconds. Consequently, the timer for the exchange of Hello packets reflects the additional delay to prevent wrong disconnection.

C. Mobility Management

In tactical networks, a device can move around in a tactical area. The mobility of terrestrial devices can be supported by conventional mobility management algorithm such as mobile IP (MIP) and proxy MIP (PMIP). The changed routing table corresponding to terrestrial networks may be reflected by using distributed or centralized mobility management method. In the distributed mobility management method, each satellite terminal exchanges a routing table with other satellite terminals which are registered on the routing table. However, the distributed mobility management method causes the increase in the control messages because a satellite terminal individually exchanges the routing table with next-hop satellite terminals. Thus, we suggest the centralized mobility management method for routing table update in the satellite networks. In this method, a control center for distributed satellite networks collects the changed routing information on terrestrial networks and then it transfers the updated routing table to all satellite terminals that are on their own networks.

The mobility of satellite terminal can not have an effect on the change of the routing table because a satellite terminal can access to an NCC or a hub everywhere. Thus, a satellite terminal maintains the connection with a control center regardless of the geographical location.

If a satellite terminal changes a current connection with another hub, the IP address of the satellite terminal should be reallocated for the efficient management of routing information. Fig. 6 depicts a mobility scenario of a satellite terminal. The case (a) and (b) represent scenarios when the IP address of the satellite terminal is not changed and is changed, respectively. Table III represents the routing tables of Hub 1 and Satellite terminal 2 (S2) in case (a) and (b). From the results, in case (a), the size of routing table for the other routers and hubs increases because the host-specific routing is needed for the moved satellite terminal. On the other hand, in case (b), the other routers and hubs can reduce the size of the routing table by using network-specific routing. Therefore, the IP address for a satellite terminal which changes the connection from a hub to the other hub should be reallocated to reduce the size of routing table of the routers and hubs.

V. Conclusion

In this paper, we considered the research issues related to routing in the CSTNs. For the employment of the dynamic routing algorithm in the CSTNs, we addressed a number of issues that include a network architecture, the exchange of the control messages, the resource allocation for the control messages, and mobility management. We also suggested a number of solutions for efficient routing in the CSTNs. From the evaluation results, it is expected that the solutions can
Table III
ROUTING TABLE

<table>
<thead>
<tr>
<th>Case (a)</th>
<th>Hub1’s routing table</th>
<th>S2’s routing table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination</td>
<td>Next hop</td>
<td>Destination</td>
</tr>
<tr>
<td>Subnet 1</td>
<td>S2</td>
<td>Subnet 1</td>
</tr>
<tr>
<td>Subnet 2</td>
<td>S2</td>
<td>Subnet 1’s R</td>
</tr>
<tr>
<td>AS2</td>
<td>Hub2</td>
<td>AS2</td>
</tr>
<tr>
<td>S1</td>
<td>Hub2</td>
<td>S1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case (b)</th>
<th>Hub1’s routing table</th>
<th>S2’s routing table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination</td>
<td>Next hop</td>
<td>Destination</td>
</tr>
<tr>
<td>Subnet 1</td>
<td>S2</td>
<td>Subnet 1</td>
</tr>
<tr>
<td>Subnet 2</td>
<td>S2</td>
<td>Subnet 1’s R</td>
</tr>
<tr>
<td>AS2</td>
<td>Hub2</td>
<td>AS2</td>
</tr>
</tbody>
</table>

contribute to employing the CSTNs for tactical networks in terms of the following aspects.

- Network architecture design of the CSTNs
- Modification of dynamic routing protocol for a satellite
- Increase in channel utilization over a satellite link
- Decrease in control overheads for dynamic routing

In the future, we will study on the routing cost metric of OSPF to reflect the characteristics of satellite links.

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