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Earth Stations Deployment for Maximizing System Throughput in Satellite/Solar-Powered Mesh Integrated Network

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***Abstract*—After a disaster strikes, the disaster victims usually become isolated and unable to utilize communication services for an extended period of time. Therefore, it is essential to establish a communication network that can operate when there is no power or infrastructure. In this paper, we focus on Satellite/Solar-powered Mesh Integrated Networks (SMIN), which are composed of a communication satellite, Earth Stations (ESs) and solar-powered Mesh Routers (MRs). A SMIN can connect to external networks via satellite and provide communication services in a large area through the wireless mesh network (WMN). To maximize the amount of communication traffic from the WMN, we aim to optimize the number of ESs and its deployment. When the number of ESs increases, the hop count between a MR and its closest ES decreases, thus resulting in an improved connectivity in the route. However, since the ESs share the bandwidth of satellite, allocated bandwidth to each ES decreases as the number of ESs increases. Therefore, we aim to optimize the number and deployment pattern of ESs. Additionally, we validate the amount of aggregated traffic that can be sent to the satellite through numerical analysis.**

I. Introduction

After large scale disasters, such as the Great East Japan Earthquake and Tsunamis on March 11, 2011, electricity and communication infrastructures within the affected area are damaged or totally destroyed [1]. In a disaster situation, it is difficult to quickly restore the network infrastructures and power supplies. Therefore, many people cannot use communication services over an extended period of time. On the other hand, after a disaster strikes, the demand for communication services greatly increases because disaster victims will try to gather disaster information or attempt safety confirmation of their family members or friends. Therefore, it is essential to establish a communication network that can accommodate a large number of people in the disaster area where there are no available infrastructures.

There are two types of networks that are suitable for disaster situations: satellite networks and Wireless Mesh Networks (WMNs) . Satellite networks are resilient to disasters. Since communication satellites are in a high altitude orbit, they are unaffected by ground disasters while being able to provide connectivity to one third of the Earth's surface at any given time. Users of satellite networks can connect to a communication satellite by setting up an earth station (ES). The

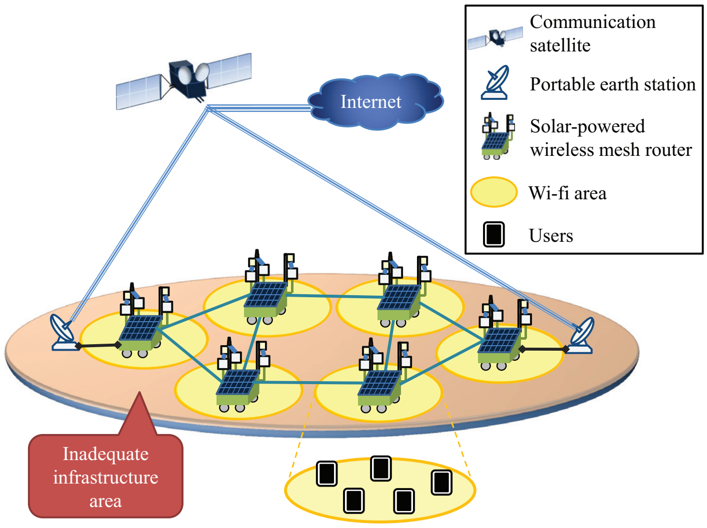

Fig. 1: Satellite/Solar-powered Mesh Integrated Network.

ESs can be carried and set up at many different locations [2]. By using these devices, people in disaster areas can access external networks through the satellite network. On the other hand, the WMN is suitable for disaster areas because of its flexibility [3] [4]. The WMN consists of many mesh routers (MRs). The MRs connect wirelessly with one another in a multi-hop fashion and can provide network access for disaster victims. In addition, solar-powered MRs receive much attention in the field of disaster-resilient networks [5]. Solar-powered MRs can operate solely with the energy generated from the equipped solar panels. Therefore, disaster victims can communicate even if existing electricity and communication infrastructures are not available. In this paper, we focus on a Satellite/Solar-powered Mesh Integrated Network (SMIN) that combines satellite network and solar-powered WMN. This network consists of a communication satellite, some portable ESs and solar-powered MRs, as shown in Fig. 1. It can provide Internet connectivity to the disaster area via satellite, and extend the communication area through WMN if existing infrastructures are unusable. Therefore, people in the disaster area can use communication services for activities such as safety confirmation. However, in the solar-powered WMN, communication traffic is restricted because any given solar-powered MRs can become unavailable due to instability of solar power generation and consumption. In order to increase the total number of users that can use the connectivity services at any given time, it is essential to maximize the amount of traffic from each ES to the satellite. Thus, we consider the trade-off relation between route retention and allocated bandwidth of ESs to improve the amount of traffic in the satellite link. The route retention is the probability that the traffic will be able to flow from each MR to the nearest ES. The allocated bandwidth is the traffic capacity of each ES. The route retention and the aggregated traffic from the MRs to the satellite depend on the deployment of the ESs. By calculating the expected value of the traffic and capacities, we determine the ESs deployment which can maximize the amount of aggregated traffic to the satellite and result in maximal system throughput.

The remainder of this paper is organized as follows. Section II introduces satellite networks and solar-powered WMNs. Section III describes the assumed SMIN and its network model. Section IV explains the trade-off relationship and defines the objective function to maximize the satellite traffic. Section V shows the evaluated results of the optimal deployment of ESs. Finally, Section VI concludes the paper.

II. Existing satellite network and WMN

In this section, we introduce satellite networks and solar-powered WMNs in disaster situations.

A. Satellite Networks

Satellite networks provide a mean of communication between the disaster area and unaffected areas via satellites. In geostationary satellite communication, the satellite's orbit altitude is approximately 36,000km and its position in the sky remains the same from the perspective of a stationary observer on Earth. ESs need a fixed satellite antenna to communicate with geostationary satellites. An ES can obtain a stable communication with the other ESs via the satellite. During the Great East Japan Earthquake, many satellite communication technologies were utilized, such as the satellite phone and video-conference. Satellite phones are common and useful in disaster areas because cellular phone would not be available due to damaged base stations [6]. Satellite phone service can be used for emergency contact, conduct of restoration work, and temporary public phones for evacuation centers. Furthermore, Wideband InterNetworking engineering test and Demonstration Satellite (WINDS) achieves a high speed link of 1.2Gbit/s [7]. WINDS provided High-definition TV conference system for each ministry and agency in the disaster area during the previously mentioned disaster.

B. Terrestrial Solar-Powered Wireless Mesh Networks

The terrestrial solar-powered WMN provides communication links in locations without power supply. In a disaster area, electricity supply will be damaged and it is difficult to restore power. Solar-powered MRs can obtain its energy through solar panels and perform communication autonomously. Therefore, we can use communication connectivity by constructing a solar-powered WMN in the disaster situation. However, solar power generation is unstable because the amount of energy generated from the solar panels depends on daylight. Thus, there are resource management schemes to maximize the energy sustainability of the network. [8] proposed a scheme to improve the energy sustainability of the mesh access points, considering placement issue and variable energy charging capabilities. [9] proposed adaptive resource management and admission control schemes, considering the intermittently available capacity of the energy supply.

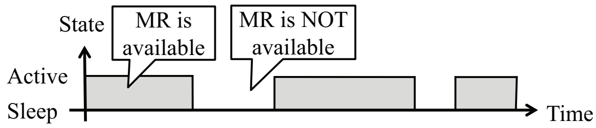

Fig. 2: A state change graph of a solar-powered MR.

III. Assumed Network and system model

In this section, we explain about SMIN and assumed network. Moreover, we describe the considered network through a mathematical model.

A. Network and System Structure

Our considered network consists of a communication satellite, ESs and solar-powered MRs. In this network, disaster victims can connect to external networks, such as the Internet, via the communication satellite through the WMN. We explain the assumed different networks and the integration process as follows:

1) Construction of the WMN:

After a disaster, we first deploy the solar-powered MRs and construct the WMN in the disaster area. Each MR is interconnected and relays the local traffic sent by the adjacent MRs. Additionally, MRs also function as access points and provide network connectivity and services to disaster victims. In addition, all of the MRs are also equipped with solar panels and rechargeable batteries for deployment in areas without electricity. We assume that each MR periodically changes its state between active and sleep due to energy management. In solar-powered MRs, the operational time may vary depending on the amount of generated power and consumption rate, or the scheduling policy of the sleep state. Therefore, the MRs change their own active or sleep state in terms of time as shown in Fig. 2. In sleep state, the MR shuts down and stops all communication to decrease power consumption and recharge its battery. The state change of each MR affects not only traffic on its own communication range but also the traffic flow of associated links and traffic routes. Therefore, we define availability as the expected value of operating time.

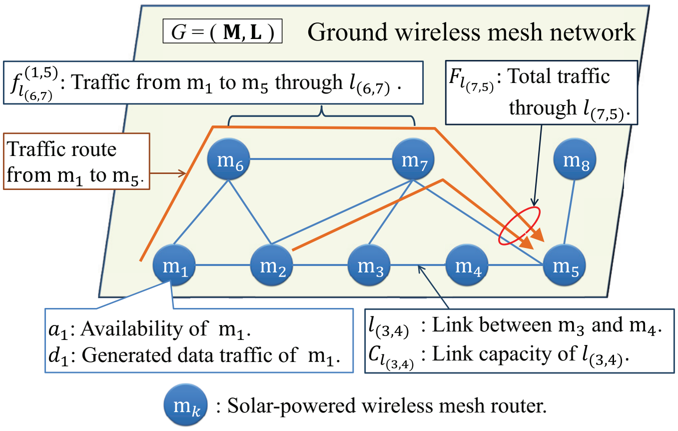

Fig. 3: Ground WMN and network parameters.

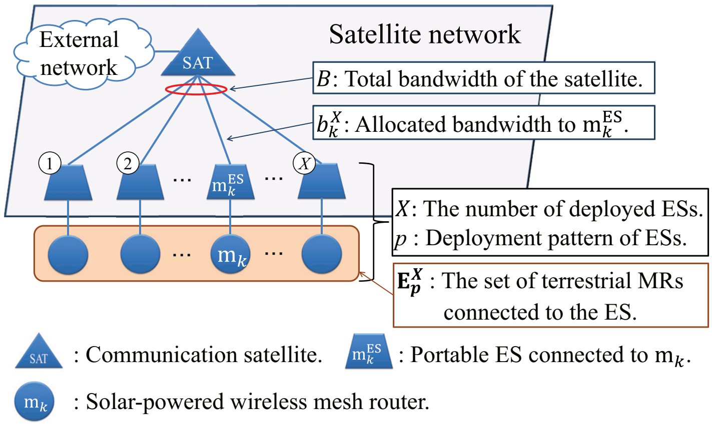

Fig. 4: Satellite network and parameters of the deployed ESs.

The availability is the probability of the MR being in active state at a certain time. Low availability means that the MR frequently enter sleep state and communication services are often not available. In addition, we define the route retention as the expected value of availability in a specific traffic route. When traffic passes through some MRs by multi hop relay transmission, all of the MRs must be in active state. Therefore, route retention is the expected value of availability for the transmission between MRs.

2) Integration of satellite network:

Secondly, we connect some ESs to the MRs through cable and integrate the satellite network into the WMN. The satellite network takes the form of a star topology, which is composed of a satellite as a hub and ESs as terminals. We assume that all of the MRs can connect to any of the ESs. Therefore, the connected MRs can use the link between the ESs and the communication satellite. It is assumed that a fixed directional antenna is used to enable large capacity and stable communication links. Thus, the satellite is also assumed to be geostationary. The satellite also communicates with a large ES in any ground satellite management center and connect to the external network. The ground center allocates the bandwidth of the satellite communication using time-division multiplexing. We assume that the bandwidth is divided equally to each MR because the ground center cannot assess the state of the isolated disaster area. In addition, it is difficult to allocate resources dynamically due to hardware constraint. After these processes, in SMIN, disaster victims can use the Internet connection via satellite, ESs and WMN.

B. Wireless Mesh Network Model

Fig. 3 shows an example of the considered model of WMN. In this model, we use an undirected graph $G = (\mathbf{M}, \mathbf{L})$ to represent the network topology. $\mathbf{M} = \{\mathrm{m}_1, \mathrm{m}_2, \cdots, \mathrm{m}_{N_{\mathrm{MR}}}\}$ are the solar-powered MRs, where $|\mathbf{M}| = N_{\mathrm{MR}}$. $\mathbf{L}$ is the set of direct connections between MRs, and $l_{(i,j)} \in \mathbf{L}$ is the link between m_i and m_j. In addition, $C_{l_{(i,j)}}$ is the original capacity of $l_{(i,j)}$. We set the expected value of data traffic demand generated from the users under the coverage of m_k to d_k. Moreover, we define the availability of m_k as a_k. The availability satisfies the following constraint:

$$0 \leq a_k \leq 1. \quad (1)$$

The route retention of a route from m_u to m_v is defined as $A_{(u,v)}$, which is expressed as the product of the availability of the MRs in the route. The $A_{(u,v)}$ also satisfies the following constraint:

$$0 \leq A_{(u,v)} \leq 1. \quad (2)$$

A MR sends data traffic and the MRs in the route relay that traffic to the next hop. The transmission is successful if every MR in the route is available. We express the amount of traffic from m_u to m_v passing through $l_{(i,j)}$ as $f^{(u,v)}_{l_{(i,j)}}$. The actual amount of traffic is less than the original generated traffic of m_u because the traffic flow is divided into each destination or restricted by link capacity of the traffic route, as follows:

$$0 \leq f^{(u,v)}_{l_{(i,j)}} \leq d_u. \quad (3)$$

In addition, the expected value of total traffic passing through $l_{(i,j)}$ at a certain time, $F_{l_{(i,j)}}$, depends on the availability and must be less than the capacity $C_{l_{(i,j)}}$, as follows:

$$F_{l_{(i,j)}} = \sum_{\mathrm{m}_u, \mathrm{m}_v \in \mathbf{M}} f^{(u,v)}_{l_{(i,j)}} \cdot A_{(u,v)} \leq C_{l_{(i,j)}} \cdot a_i \cdot a_j. \quad (4)$$

In Fig. 3, MRs m_1 through m_8 construct a WMN. When m_1 sends data traffic to m_5, in this case, the traffic route is calculated as $(\mathrm{m}_1, \mathrm{m}_6, \mathrm{m}_7, \mathrm{m}_5)$ through a minimum hop approach. Also, m_2 sends traffic to m_5. Therefore, the total traffic through the link $l_{(7,5)}$, $F_{l_{(7,5)}}$, is the sum of the $f^{(1,5)}_{l_{(7,5)}}$ and $f^{(2,5)}_{l_{(7,5)}}$.

C. Satellite Network model

Fig. 4 shows an example of the considered model of satellite network. We deploy and connect the ESs to the MRs in the WMN. When the maximum number of deployable ESs is N_{ES}, we can choose the number of deployed ESs, X, within a range of $1 \leq X \leq N_{\mathrm{ES}}$. If we deploy X ESs, the

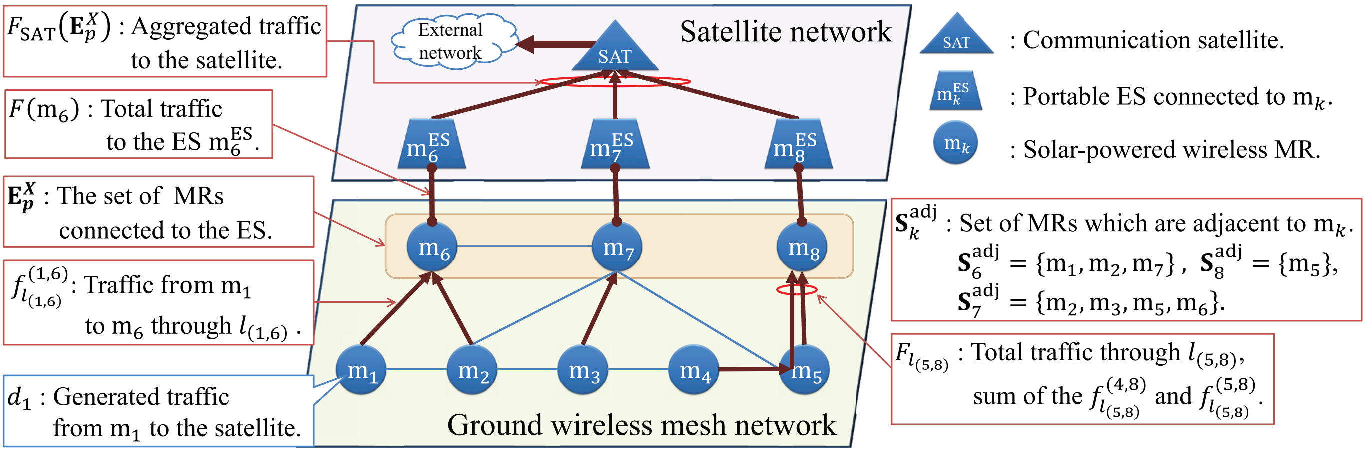

Fig. 5: Model of a SMIN and aggregated traffic flow.

total number of deployment patterns, P, is described as the following combination:

$$P = \binom{N_{\text{MR}}}{X}. \tag{5}$$

We denote the p^{th} set of MRs which are connected to the ES when the number of deployed ES is X by $\mathbf{E}_p^X$, where $1 \leq p \leq P$ and $|\mathbf{E}_p^X| = X$. p is an identification number of each deployment pattern, and should satisfy the following:

$$p \neq p' \quad \Rightarrow \quad \mathbf{E}_p^X \neq \mathbf{E}_{p'}^X \tag{6}$$

For example, the elements of $\mathbf{E}_p^X$ could be expressed as $\{\text{m}_2, \text{m}_3, \text{m}_5, \cdots, \text{m}_{N_{\text{MR}}-1}\}$. We denote the ES which connects to the MR m_k as m_k^{ES}. Additionally, we assume that the allocated bandwidth from the satellite is divided equally between the ESs. We define the total bandwidth of the satellite as B. Therefore, the allocated bandwidth to a m_k^{ES}, when the number of deployed ESs is X, b_k^X, is calculated as follows:

$$b_k^X = \frac{B}{X}. \tag{7}$$

In Fig. 4, X ESs are connected to X MRs of the existing WMN. The set of MRs which are connected to ESs, $\mathbf{E}_p^X$, depends on the number of deployed ESs, X, and the deployment combination pattern, p.

IV. Analysis of Network traffic and Earth Station Deployment

In this section, we aim to realize the optimal deployment of ESs. In order to optimize the number of ESs and its deployment pattern, we consider the availability of the MR.

A. Optimization Objective

In our assumed network, all of the traffic will be concentrated at the satellite link because the satellite link is the only way to connect to external networks. Therefore, we aim to maximize the usage efficiency of the satellite bandwidth, which results in a maximal system throughput. We assume that the terrestrial WMN is already constructed and each parameter of the WMN is given. In addition, the total bandwidth of the satellite and the maximum number of deployable ES are known. According to these information, we attempt to optimize the deployment of ES and maximize the system throughput.

B. Trade-off relation

To maximize the usage efficiency of the satellite link, we need to consider the trade-off relationship between route retention and allocated bandwidth. The relation depends on the number of ESs. If the number of ESs increases, the route retention improves but allocated bandwidth to each ES decreases. The logic behind this is described as follows.

1) Route retention: If we increase the number of ESs, the aggregated traffic to the satellite may increase. That happens because a larger number of ESs increases route retention because the hop count of related route may decrease. An insufficient route retention may decrease the traffic from each MR to the ESs.

2) Allocated bandwidth: The deployed ESs share the satellite bandwidth equally. Therefore, if we add some ESs, the allocated bandwidth of each ES decreases in inverse proportion to the number of ESs. An insufficient allocated bandwidth may decrease the aggregated traffic to the satellite by shortage of ES's capacity.

As mentioned above, there is a trade-off relationship between route retention and allocated bandwidth with the number of deployed ESs. Therefore, there is an optimal number of ESs where usage efficiency of the satellite bandwidth would be maximized. Additionally, the deployment pattern of the ESs affects the route retention of each traffic route. Thus, it is necessary to optimize the deployment of ESs.

C. Objective function

To optimize the number of ESs and its deployment pattern, it is required to determine the optimal set of $\mathbf{E}_p^X$, $\mathbf{E}_{p_{\text{opt}}}^{X_{\text{opt}}}$. Fig. 5 shows an example of the considered integrated network and traffic flow to the satellite. The aggregated traffic to the satellite is sent from the ESs. The ESs receive traffic from the MRs which send the traffic to the ES. When we try certain deployments of the ESs based on $\mathbf{E}_p^X$, we calculate the amount of expected value of traffic to each ES. Total traffic received on an ES $\mathrm{m}_k^{\mathrm{ES}}$, $F(\mathrm{m}_k)$, is sum of the traffic from each link to m_k and generated traffic of m_k as follows:

$$F(\mathrm{m}_k) = d_k \cdot a_k + \sum_{\mathrm{m}_i \in \mathbf{S}_k^{\mathrm{adj}}} F_{l_{(i,k)}}, \tag{8}$$

where $\mathbf{S}_k^{\mathrm{adj}}$ is set of the MRs which are adjacent to m_k and have a direct link to m_k. In addition, each ES relays the received traffic within their allocated bandwidth. Therefore, the expected value of aggregated traffic to the satellite, $F_{\mathrm{SAT}}(\mathbf{E}_p^X)$ is calculated through the sum of the traffic from all ESs as follows:

$$F_{\mathrm{SAT}}(\mathbf{E}_p^X) = \sum_{\mathrm{m}_k \in \mathbf{E}_p^X} \min\left(F(\mathrm{m}_k), b_k^X\right). \tag{9}$$

We define the Eq. 9 as the objective function and aim to maximize the aggregated traffic. Therefore, we determine the set of ESs that maximizes Eq. 9 as an optimal deployment of ESs as follows:

$$\mathbf{E}_{p_{\mathrm{opt}}}^{X_{\mathrm{opt}}} = \arg\max_{\mathbf{E}_p^X} F_{\mathrm{SAT}}(\mathbf{E}_p^X). \tag{10}$$

In Fig. 5, $\mathbf{E}_p^X = \{\mathrm{m}_6, \mathrm{m}_7, \mathrm{m}_8\}$ and each MR sends uplink traffic to the external network through the ESs and the satellite. For example, m_1 selects $\mathrm{m}_6^{\mathrm{ES}}$ as the ES and sends the traffic to m_6. The ES connected to m_6 receives the traffic from $\mathrm{m}_1, \mathrm{m}_2, \mathrm{m}_6$, and sends the sum of the traffic to the satellite. Also, the satellite receives traffic from each ES and sends the aggregated traffic to the external network.

V. Numerical Analysis

In this section, we analyze the usage efficiency of the satellite bandwidth and the optimal deployment of ESs. After the analysis, we show the difference of the optimal deployment pattern with changing network situations.

A. Parameter Setting

We set the number of MRs, N_{MR}, to 25, and arrange the MRs to form a 5×5 grid linked structure. The maximum number of ESs, N_{ES}, is 10 and we calculate the optimal number of ESs within the range of 1 to 10. We set the bandwidth of the communication satellite, B, to 155Mbps, which is maximum data rates of regenerative mode of WINDS [7]. We assume that the link capacity between each MR is sufficiently large for a high frequency band and directional beam traffic. In this work, we attempt each number of deployable ESs and all of their deployment patterns. To evaluate the optimal deployment of ESs in various network states, we change the traffic distribution and value of the availability of each MR. We set the data traffic of each MR as the product of the number of users within the MR's coverage and the expected value of traffic per one user. Disaster victims tend to use particular applications such as confirmation of safety, or we may put a restriction on the applications that users can use. Therefore, we assume that the expected value of data traffic depends on the number of users. We set the number of users in each MR to three patterns of dispersion intensity: low, middle and high. In low and middle dispersion, the users are distributed according to a Gaussian distribution and its variance. We assume that the WMN is constructed with a central focus on the evacuation center and disaster victims who gather there. Thus, the number of users in the center MR is bigger than in the outer MRs. In low dispersion, the value of the variance of the Gaussian distribution is 0.5, users concentrate in center MRs, and outer MRs have few users. In middle dispersion, the value of the variance of the Gaussian distribution is 1.5 and users are spread across the overall WMN. In high dispersion, the users are distributed according to uniform distribution and all MRs have the same number of users. We set the total number of users under the WMN to 1550 in all cases, and the traffic per user to 100kbps. Additionally, we vary the availability of each MR, a_k, to 0.8, 0.6 and 0.4.

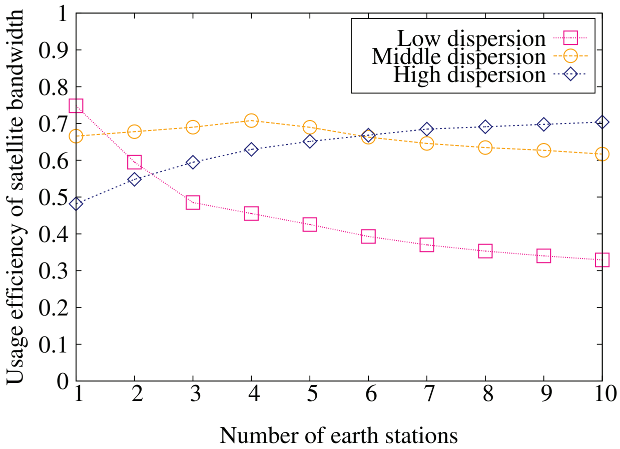

Fig. 6: Usage efficiency of the satellite bandwidth with each number of ESs.

B. Numerical Results

Fig. 6 shows the results of the expected value of usage efficiency of the satellite bandwidth, when the number of ESs varies. The usage efficiency of the satellite bandwidth, $U^{\mathrm{SAT}}(X)$, is calculated as follows:

$$U^{\mathrm{SAT}}(X) = \frac{\max_{1 \le p \le P} F_{\mathrm{SAT}}(\mathbf{E}_p^X)}{B}, \quad (1 \le X \le 10). \tag{11}$$

We set the availability to 0.8. According to this result, when users are distributed with low dispersion, we obtain 1 as the optimal number of ESs which leads to the most efficient value. In low dispersion, most of the users are under the center MR. Therefore, we should deploy one ES to the center and allocate a lot of bandwidth to it. If we add some ESs, the number of users in the MR which are connected to the added ESs is low and the ESs waste the allocated bandwidth. In middle dispersion, we obtain 4 as the optimal number of deployed ESs. If the number of ESs decreases, the route retention of each MR and the amount of aggregated traffic to the ESs decreases. However, since more users concentrate in the center MR, excessive numbers of ESs result in shortage of allocated bandwidth. Therefore, usage efficiency does not improve even if the number is lower or higher. In high dispersion, we obtain 10 as the optimal number of deployed ESs. Since all MRs have the same number of users, we deploy ESs in an even interval to resolve the traffic bias. Therefore, we deploy the maximum number of ESs to improve the route retention because traffic is evenly aggregated to each ES. Thus, we can determine the optimal number of ESs and its deployment.

Fig. 7 shows the optimal number of ESs calculated by Eq. 10, when the variance of user distribution is changed. In this pattern, we fix the availability of each MR to 0.8, 0.6 and 0.4. When dispersion is low, users concentrate in the center, which leads to a traffic bias. Therefore, the optimal number of ESs is small in order to allocate a lot of bandwidth to be center ES. However, if availability is low, the traffic is sharply restricted and we need to deploy some ESs to increase the route retention. With middle dispersion, users are distributed all over the MRs. Thus, the optimal number of ESs is higher than in the low dispersion to minimize the hop count from all MRs to their closest ESs. When dispersion is high, the optimal number of ESs becomes equal to the maximum number of ESs regardless of availability as explained in the previous paragraph. Therefore, the optimal number depends on traffic distribution and availability.

As shown above, we show the optimal number of ESs and their deployment for various situations. The traffic transmitted from each ES depends on route retention and allocated bandwidth. Therefore, to increase usage efficiency of the satellite bandwidth, we should determine the optimal number and deployment of ESs.

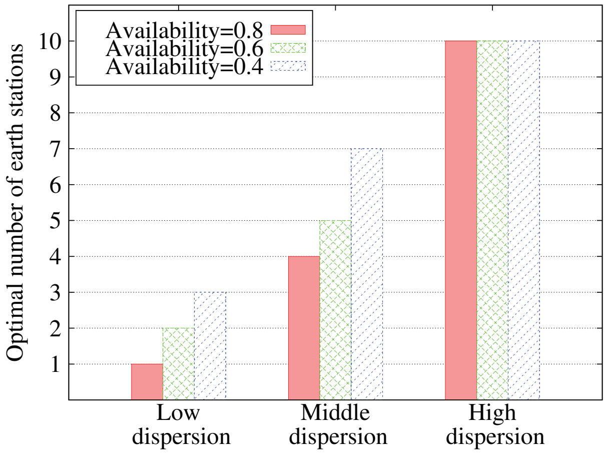

Fig. 7: Optimal number of ESs when user distribution is varied.

VI. Conclusion

In disaster areas, a network that can operate without existing infrastructures is required. Satellite networks and solar-powered WMNs can provide communication on disaster situations, which leads us to SMINs. In SMINs, satellite network acts as a gateway to external networks while a solar-powered WMN provides network access to disaster victims. We aim at maximizing the amount of traffic and usage efficiency of the satellite bandwidth so that system throughput may increase. However, in order to enhance the high usage efficiency of the satellite bandwidth, the optimization of the number and deployment of ESs is necessary. The deployment problem causes a trade-off between route retention and bandwidth allocated by the satellite to each ES. To prove the existence of an optimal deployment, we proposed an objective function to determine the optimal number and deployment pattern of the ESs. In this work, we numerically analyze the network and attempt every patterns of deployment for each number of deployable ESs. After the trial, the deployment pattern which achieved the most efficient value of usage efficiency of the satellite bandwidth was determined. In addition, we analyzed the optimal deployment numerically in different network states. We also compared the optimal number of ESs for different situations.

References

[1] M. Kobayashi, "Experience of Infrastructure Damage Caused by the Great East Japan Earthquake and Countermeasures against Future Disasters," *Communications Magazine, IEEE*, vol. 52, no. 3, pp. 23–29, Mar. 2014.

[2] T. Takahashi, B. Jeong, M. Okawa, A. Akaishi, T. Asai, N. Katayama, M. Akioka, N. Yoshimura, M. Toyoshima, R. Miura, and N. Kadowaki, "Disaster Satellite Communication Experiments using (WINDS) and Wireless Mesh Network," *16th International Symposium on Wireless Personal Multimedia Communications (WPMC)*, pp. 1–4, Jun. 2013.

[3] M. Fouda, H. Nishiyama, and N. Kato, "A Novel Heuristic-based Traffic Distribution Method for Disaster Zone Wireless Mesh Networks," *2012 1st IEEE International Conference on Communications in China (ICCC)*, pp. 179–184, Aug. 2012.

[4] T. Hadhrami, Q. Wang, M. Crowe, and C. Grecos, "UrgentMesh: Wireless Mesh Networks with DVB-Satellite for Emergency Management," *Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), 2011 3rd International Congress on*, pp. 1–6, Oct. 2011.

[5] T. Suzuki and Y. Shibata, "Self Power Supplied Wireless Disaster Information Network," *Advanced Information Networking and Applications Workshops (WAINA), 2010 IEEE 24th International Conference on*, pp. 721–726, Apr. 2010.

[6] V. Spiridonov, "INMARSAT SYSTEMS AND SERVICES," *Proceedings of International Conference on Satellite Communications*, vol. 1, pp. 45–52, Oct. 1994.

[7] N. Katayama, T. Takahashi, M. Akioka, T. Terada, M. Ohkawa, T. Asai, A. Akaishi, S. Nagai, N. Yoshimura, Y. Takayama, and R. Suzuki, "Support Activity using WINDS Satellite Link in the 2011 off the Pacific coast of Tohoku Earthquake," *14th International Symposium on Wireless Personal Multimedia Communications (WPMC)*, pp. 1–5, Oct. 2011.

[8] L. Cai, H. Poor, Y. Liu, T. Luan, X. Shen, and J. W. Mark, "DIMENSIONING NETWORK DEPLOYMENT AND RESOURCE MANAGEMENT IN GREEN MESH NETWORKS," *Wireless Communications, IEEE*, vol. 18, no. 5, pp. 58–65, Oct. 2011.

[9] L. Cai, Y. Liu, T. Luan, X. Shen, J. Mark, and H. Poor, "Sustainability Analysis and Resource Management for Wireless Mesh Networks with Renewable Energy Supplies," *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 2, pp. 345–355, Feb. 2014.