Ballooned SKYMESH for Network Providing and Sensing Disaster Areas

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***Abstract*— As emergency communication systems for the large scale disaster, a wireless network using balloons, SKYMESH, was proposed so far. In this paper, a renewable energy based wireless ballooned network is designed to insure communication means to grasp information in disaster areas. By combining multiple ballooned wireless network nodes, a large adhoc network is automatically organized in the sky on the disaster area and can cover shelters or interrupted communication area as urgent communication means. SKYMESH is an emergency communication system for large scale disaster. As emergency communication systems for the large scale disaster of wireless network using balloons, a network construction method for SKYMESH is proposed. The proposed network construction method is implemented, and its performance is evaluated**

Keywords: Ad hoc network, Wide Area Disaster Information Network, Emergency communication, Ballooned Network

I.INTRODUCTION

Recently natural disasters such as earthquake, seismic sea wave, typhoon, hurricane in addition to annual disaster have frequently happened at many places around the world. When disaster occurs, information networks infrastructure performs very important role as the resident's communication means. However, once a disaster occurred, failures of network equipments, cutoff of communication lines and traffic congestion cannot be avoided. More reliable and robust network environment is required even though the serious damaged by disaster occurred.

As a solution of this problem, a wireless network using balloons, SKYMESH, was proposed as emergency communication systems [1]. So far, we have developed effective Wide area Disaster information Network (WDN) using Internet over the combination of both wired and wireless network[2][3]. In this information network, two important functions including resident safety information system and bidirectional video communication system between evacuation places and disaster information centre are provided [4][5][6].

However, in this WDN, system failure of network and computing facilities by disaster were not considered. In the past work, communication quality was investigated by experiment [7], [8], and remote monitoring system using SKYMESH was proposed [9], but it is hardly discussed how to construct SKYMESH networks. In the conventional mesh networks, the network construction and management methods were discussed in [10], [11]. However, it is not a good choice to use these methods for SKYMESH because SKYMESH has particular characteristics, which are not seen in the conventional mesh networks.

In this paper, a ballooned wireless network is proposed to promptly insure communication means to grasp the information with disaster area, resident's safety and relief goods on the occurrence of disaster. By combining multiple ballooned wireless network nodes, a large adhoc network is automatically organized in the sky on the disaster area and can cover shelters or interrupted communication area as urgent communication means. The Structure consists of balloon nodes, terrestrial nodes and user terminals are termed as SKYMESH. SKYMESH is an emergency communication system for large scale disaster. Then not only specialists but also people who are out of touch with network technology can construct it. SKYMESH has a peculiar characteristic, which derives from network components such as balloon nodes and terrestrial nodes.

In the followings, the system structure is described in section 2. Network Placement Scheme is explained in section 3. Network Construction Method is explained in section 4. The proposed network construction method is implemented, and its performance is evaluated by experiments in 5. Finally concluding remarks and future works are summarized in section 6.

II. SYSTEM STRUCTURE

A.Skymesh

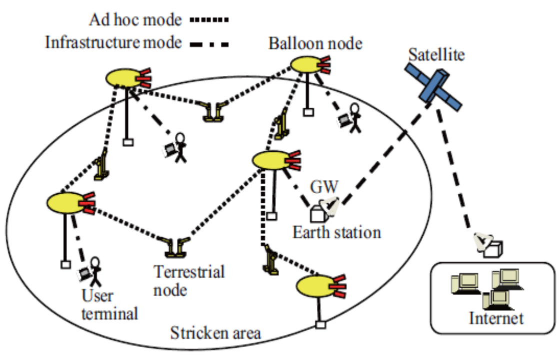

Fig. 1.An overview of SKYMESH.

Fig. 1 shows an overview of SKYMESH. SKYMESH consists of balloon nodes, terrestrial nodes and user terminals.

A balloon node is composed of a balloon hanging wireless communication equipment. The wireless communication equipment contains two IEEE 802.11 wireless LAN interfaces (IFs). One IF operates in an ad hoc mode, and constructs a backbone network of SKYMESH. The other operates as an access point (AP) for user terminals. Since the direction of the balloon changes by the wind, the IF for the backbone network connects with an omni-directional antenna. The IF for user terminals connects with a directional antenna, which is trained below.

B. Requirements for SKYMESH

From the system structure of SKYMESH, which is described in II-A, requirements for the network construction method are followings:

1) The method does not need special knowledge about network and wireless communication technologies, and can automatically construct a network only by placing nodes.

2) The balloon nodes and terrestrial nodes can be configured before sending them to the stricken area, but the settings which depend on node location and network topology cannot be set because node location is decided according to geographical features of the stricken area.

3) In order to reduce node placement costs, the number of balloon nodes and terrestrial nodes had better be as small as possible.

4) The user terminal can connect the SKYMESH network by belonging to the AP of the balloon node or the terrestrial node without any specific settings, like as hot spot services.

5) SKYMESH does not support roaming between Aps for user terminals. From requirement 3), the distance between a balloon node and a terrestrial node becomes long. Then, the area of APs is limited around the balloon node or the terrestrial node, that is, the area of APs is discontinuity. When a user terminal uses the SKYMESH network, it moves in the area of the AP by finding the balloon node in the sky.

6) Several channels are available for IEEE 802.11 wireless LAN. In order to improve network performance, the network construction method contains a channel assignment of each link.

7) If GW is available, user terminals can connect external networks via GW.

C. Balloon Structure

Fig. 2 shows a structure of ballooned wireless network node. A commercially available balloon made by vinyl chloride is used by considering its simple structure, low cost and easy utilization even though the disaster happened.

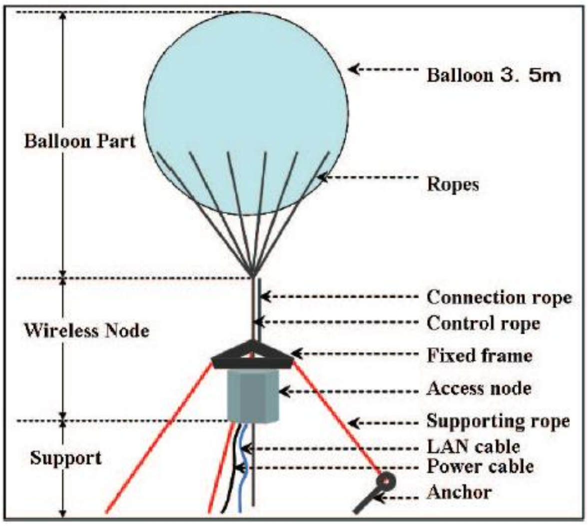

Fig. 2 Balloon Network Node

The volume size of a balloon varies depends on how much of a total weight of wireless LANs is loaded. In our case, the volume of balloon is 3.5 m3 and filled up by helium gas which provides 28 Kg as buoyancy. On the other hand, the total weight includes the balloon (8.5Kg) and wireless access node (8Kg) and the supporting ropes (1.5Kg). Thus, the residual buoyancy is 10Kg which is enough to keep the balloon 40-100 m high in the sky. The electric power for wireless network node is supplied from power battery for emergency or vehicle on the ground trough the very thin power cable.

III. METHODOLOGY

Fig. 3 shows indicates a system configuration of our proposed system which is consisted of multiple ballooned wireless network nodes, the fixed access point, mobile note PCs, wireless IP telephones. A wireless ballooned network node is consisted of two high speed wireless LANs such as IEEE802.11j in horizontal with octagonal patch antenna and IEEE802.11b,g in vertical with unidirectional communication antenna. Those wireless LANs are attached to a commercially available balloon and launched about 40-100 m high in the sky. In addition, our LAN has an auto configuration function to mutually and automatically connect to other LAN based on the power signal density. Therefore, by launching multiple ballooned wireless network nodes, in horizontal an adhoc network by IEEE802.11j is automatically organized in minimum spanning three configurations according to each power signal density in the sky.

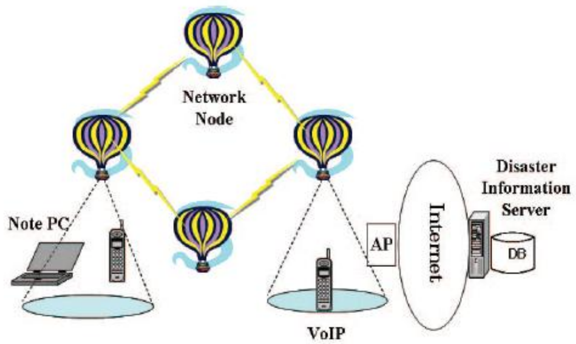

Fig. 3 Ballooned Wireless Adhoc Network in Disaster Area

The proposed system consists of multiple ballooned wireless network nodes, the fixed access point, mobile note PCs, Sensing devices and Wi-Fi Connectivity. A wireless ballooned network node is consisted of two high speed wireless LANs such as IEEE802.11j in horizontal with octagonal patch antenna and IEEE802.11b,g in vertical with unidirectional communication antenna. Those wireless LANs are attached to a commercially available balloon and launched about 40-100 m high in the sky. By launching multiple ballooned wireless network nodes, in horizontal an adhoc network by IEEE802.11j is automatically organized in minimum spanning three configurations according to each power signal density in the sky. On the other hand, vertical communication service like hotspot on the ground level is provided by IEEE802.11g LAN from 40~100m high in the sky.

The ballooned wireless adhoc network is finally connected to the fixed access point which is a gateway to Internet or wide area network where the disaster information servers (WIDIS) and other information services can be available. The mobile note PCs provide functions to register the information with resident's safety, disaster information, relief goods at shelters to the disaster information servers on Internet through the adhoc network. Omni-directional camera system is also attacked to the balloon to observe the disaster area form the sky. The images from the omni-directional mages are transmitted to the disaster headquarter. Thus, the urgent information network infrastructure in disaster area quickly is organized using the suggested ballooned wireless adhoc network. Pressure, temperature and Gas Sensors are attached to the balloon to sense the environmental parameters in disaster area. Network facility will be provided by Wi-Fi Protocol.

Fig 3 shows the sensing unit. The main objective of this unit is to find out the various environmental parameters in the disaster area. The temperature of the disaster area can be detected by means of the Temperature Sensor LM35. The Gas in the disaster area was determined by the Gas sensor MQ-7. The humidity of the disaster area was determined by humidity sensor module SY-HS-220.The data determined by these sensors were send to signal conditioner in order to convert those signals to digital. This data was transmitted to the microcontroller in order to send those signals to the server section by means of the encoder. The values can be viewed in the LCD display.

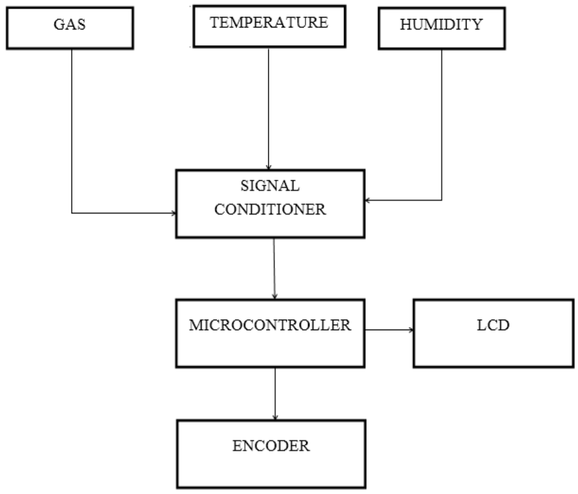

Fig.4 Sensing Unit

III. NETWORK PLACEMENT

This section describes a Network placement method for SKYMESH.

A. Requirements for Node Placement

Based on the previous work [2], which experimentally measures link quality of SKYMESH, requirements for the node placement method are decided as follows:

1) For a balloon node, there are no obstacles around an area so that the balloon can□oat safety. Since the balloon can become a sign for victims, it may be placed near by shelters.
2) The balloon node □oats at 50–100 m high.
3) The maximum distance between a terrestrial node and a balloon node is about 2.4 km [2]. The terrestrial node should be placed within 2.4 km of the balloon node.
4) It is also important that a link between the terrestrial node and the balloon node should be line-of-sight.

As the requirement 1), the balloon node had better be placed near by shelters because the shelters usually have open space for floating the balloon node, and victims will come to the shelters. It is desirable that the terrestrial node is placed between the balloon nodes at the shelters. However, if the distance between shelters is over the maximum distance of balloon-terrestrial-balloon link, that is, 4.8 km, a balloon node should be placed somewhere. The requirement 4) is not only for good communication quality of a link but also for easy adjustment for antenna direction of the terrestrial node.

B. Node Placement Procedure

When location of nodes is decided, nodes are carried to the stricken area and placed. After that, nodes are turned on, and network construction starts automatically. Following schemes are considered as the node placement procedure:

• Simultaneous construction scheme: After placing balloon nodes and terrestrial nodes, all nodes are simultaneously turned on and network construction starts.

• Individual construction scheme: Each node is turned on individually when it is placed.

• Serial construction scheme: A certain node is decided node, their neighbor nodes, and so on, are turned on sequentially.

Since node's condition seriously affects communication quality of a link in SKYMESH, location and height of balloon nodes, and location and antenna direction of terrestrial nodes should be adjusted. In the simultaneous construction and the individual construction schemes, if a node has some links, it is difficult to adjust these links simultaneously. In some cases, re-adjustments may be required. On the other hand, the serial construction scheme adjusts only a new adding node. Therefore, SKYMESH employs the serial construction scheme as an origination node. At first, the origination node is turned on. After that, neighbor nodes of the origination node, their neighbor nodes, and so on, are turned on sequentially. Since node's condition seriously affects communication quality of a link in SKYMESH, location and height of balloon nodes, and location and antenna direction of terrestrial nodes should be adjusted. In the simultaneous construction and the individual construction schemes, if a node has some links, it is difficult to adjust these links simultaneously. In some cases, re-adjustments may be required. On the other hand, the serial construction scheme adjusts only a new adding node. Therefore, SKYMESH employs the serial construction scheme.

IV. NETWORK CONSTRUCTION

Since it is preferred that small number of balloon nodes and terrestrial nodes can cover the stricken area, the SKYMESH network has sparse topology. The terrestrial node employs a directional antenna, which is trained on a balloon node. The network topology hardly changes when node placement finishes. Then, SKYMESH does not need complicated and frequent route calculation, like routing protocols [7], [8] standardized at Internet Engineering Task Force (IETF). The proposed network construction method employs simpler routing scheme, which calculates routes only when network topology changes.

The network construction requires the information about network topology and communication quality of links. The proposed method constructs a temporal network, which we called an initial network, and gathers the above information through this network. Based on the gathered information, it constructs an operation network. In the serial construction scheme of the node placement procedure, the initial network is constructed from the origination node. Therefore, the origination node gathers the information required for the operation network construction, and calculates channel assignment and routes. The procedure of the proposed network construction method is,

1) Initial network construction and information gathering,
2) Channel assignment calculation for the operation network,
3) Route calculation for the operation network, and
4) Operation network construction.

A. Initial Network Construction and Information Gathering

In this process, nodes are placed and turned on from the origination node, and the initial network is constructed. After that, the origination node gathers the information required for the operation network construction. The initial network has tree topology whose root is the origination node because only the route from the origination node to each node should be established for information gathering. The routes between any nodes are established in the operation network. Conditions for the initial network construction are the followings:

1) The origination node is decided in advance.
2) A unique IP address and common Extended Service Set Identifier (ESSID) are assigned to each node in advance. A temporal common channel is also set to every node so that every node can establish a link with its neighbor node.
3) Expected Transmission Count (ETX) [9] is employed as a metric of link quality. ETX between nodes A and B may be expressed by

$$ETX = 1/(1-Pf)(1-Pr)$$

where P_f and P_r are packet error rates from node A to node B and from node B to node A, respectively.

B. Channel Assignment Calculation for Operation Network

For the operation network, the origination node calculates the channel assignment of all IFs of nodes in the SKYMESH network so as to reduce inter-link interference. Since network topology is sparse and the terrestrial node has directional antennas in SKYMESH, interference between any two links which do not share nodes each other can be ignored. Since a balloon node has an IF for the backbone network, the same channel should be assigned to the links with its neighbor terrestrial nodes. It is possible to assign a different channel to each IF of the terrestrial node. At first, links with bad communication quality are eliminated from the link information, but the links which includes the initial network are not eliminated because of keeping the network connectivity. Then, a channel is assigned to each link so that inter-link interference can be reduced. The procedure of the channel assignment calculation is the followings:

1) Links whose ETXes exceed the pre-defined threshold are eliminated from the link information.
2) Nodes are listed in order of the number of descendants in the initial network.
3) The node which has the most descendants is selected among nodes at which channels are not assigned. For the selected node, channels are assigned to its IFs as follows:

i) If a channel is not assigned to the IF for the AP, this IF is selected. Otherwise, the IF which has the most descendants is selected among IFs at which a channel is not assigned.
ii) If there is more than one channel which is not assigned at IFs, one of them is randomly assigned at the selected IF. Otherwise, an arbitrary channel except for the channel of the IF for the AP is assigned.
iii) The same channel is assigned to the IF of the neighbor node which is faced by the selected IF. If the neighbor node is a balloon node, the same channel is assigned to neighbor nodes of the balloon node.

iv) The above procedure is repeated until channels are assigned to all IFs of the selected node.

4) Step 3) is repeated until channel assignment finishes for all nodes.

V. EXPERIMENTAL RESULTS

The sensing unit uses various sensors to detect various environmental parameters like Gas, Temperature and Humidity in the disaster area in order to provide recovery in affected areas. The temperature of the disaster area can be detected by means of the Temperature Sensor LM35. The Gas in the disaster area was determined by the Gas sensor MQ-7. The humidity of the disaster area was determined by humidity sensor module SY-HS-220.

The Fig 5 shows the schematic diagram of the simulation circuit of the sensing unit of my project work. In this circuit I have included the necessary components which were needed to find out various environmental parameters in the disaster area through the wireless balloned network.

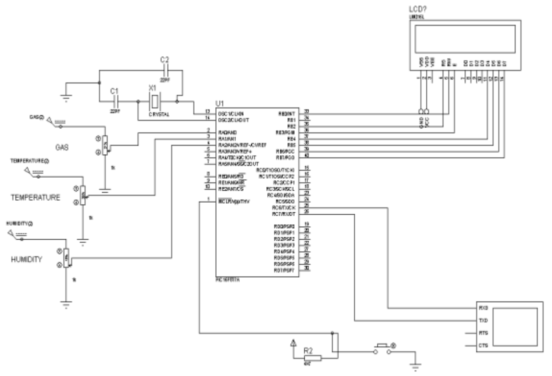

Fig.5 Sensing Unit Simulation Circuit

The Fig 6 shows the simulation output i.e. Virtual terminal output of the sensing unit. This virtual terminal window shows the estimated gas, estimated temperature and estimated humidity in the disaster area through Wireless Ballooned Network.

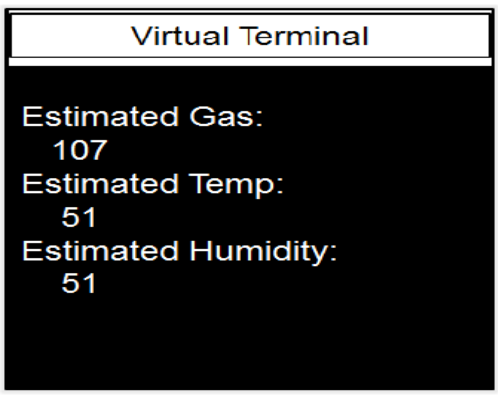

Fig. 6 Sensing Unit simulation output

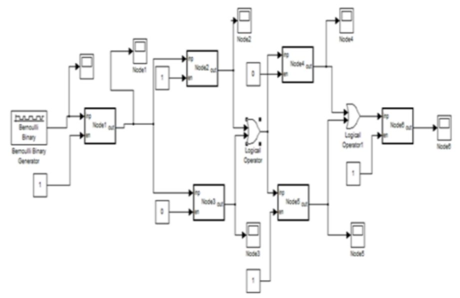

Fig. 7 Network Providing Unit Circuit

VI. CONCLUSIONS

In this paper, a ballooned wireless network was proposed to promptly insure communication means to grasp the information with disaster area, resident's safety and relief goods on the occurrence of disaster. By combining multiple ballooned wireless networks, an adhoc network is organized in the sky on the disaster area, shelters or interrupted communication area as urgent communication means. A Prototype system was constructed to evaluate its function and performance through three disaster application such as WIDIS, VoIP, and Omni-directional video surveillance system. Through this evaluation of the prototype system, the usefulness of our suggested ballooned wireless adhoc network system could be verified.

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