Integrated Wireless Communication System Using MANET for Remote Pastoral Areas of Tibet

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Abstract: To reduce the network deployment cost and provide voice, message and low rate data services in remote pastoral areas of Tibet effectively, an integrated wireless communication system utilizing MANET (Mobile Ad hoc Network) is proposed. The sparse mobile devices, assisted with the solar-powered multi-functional standing stations mainly on networking maintenance and routing arrangement, self-organize into a MANET. The topology of the standing stations is designed for networking robust and to simplify the routing method and energy strategy. Then in the OMNeT++ (Objective Modular Network Test bed in C++) simulation, the energy consumption is analysis while adjusting routing with the different energy status of the standing stations. The result shows that the standing stations should adjust routing as well as control the mobile devices' activity level according to the energy states of the standing stations and their adjacent mobile devices.

Keywords: wireless communication; system; OMNeT++; MANET; Tibet

I. INTRODUCTION

In vast remote rural and pastoral areas of Tibet Autonomous Region, some certain mobile communication demands, mainly including the nomadic herdsmen demands during the grazing season, irregularly scheduled scientific investigating/emergency missions demands, and long term environment monitoring task demands, have hardly been satisfied due to the lack of certain economic convenient mobile communication tools.

To meet them through the expansion of existing 2G/3Gcellular systems is extremely uneconomical, because these communication demands are not only relatively sparsely distributed in a very vast land but also mostly seasonal or unexpected. Another possible solution is to use satellite communications, but they are too expensive for civil uses. With the economic and social development of Tibet and the country, these demands need to be satisfied more and more urgently [1][2]. To address the faced problem, we propose to build an integrated wireless communication system using the MANET (Mobile Ad hoc Network) concept in this paper.

In the expected system, the key problem to be considered is how to realize mobile communication for mobile users. To utilize 'MANET' concept is the preferred. A MANET is a 'temporary' self-configuring multi-hop network of mobile users connected by wireless, which does not rely on available fixed infrastructure. Each user is free to move independently, and will therefore change its links to other users at times. Each is equipped to continuously maintain the information required to properly route traffic. Such network may operate by itself or be connected to the larger network. So to network using MANET is flexible, convenient and rapid. At present, it is mainly used in military tactics communication and emergency communication field. In recent years, along with the mobile equipment miniaturization and construction cost lowering, MANET has begun to participate in personal communication network establishment and to be becoming an important form of network accessing [3][4][5].

In this particular scenario of Tibet, there are two main technical problems need to be resolved while establishing an integrated wireless communication system utilizing MANET:

The mobile users are so scarcely distributed that they can not self-network and connect directly with other ground communication system.

The mobile users' devices are extremely energy-constraint, though the nomadic herdsmen or others would carry a small solar power plant (or mixed with a small wind power unit) with one or two solar panels.

In the next section of this paper, the integrated wireless communication system utilizing MANET is presented. Then, the analysis and design of the network topology are proposed, and how the network elements are organized and how they take functionalities are described specifically. In the fourth Section, the routing method and energy strategy is researched and evaluated through simulations. Lastly, this paper is concluded.

II. Integrated Wireless Communication System

In the remote pastoral areas in Tibet, there exit areas of coverage of the cellular system base station only near the very main roads. When the mobile users are within the radio coverage of cellular network, they just use the available system. But while they are standing far away, they will self-organize into a MANET with the called standing stations that will be specifically described in the next section. The established WSNs (Wireless Sensor Networks) for monitoring could be virtual mobile users of MANET.

As shown in Fig.1, the MANET is the transmission network for mobile user-to-user communications, and also acts as the transit network for user-to-cellular-network communications. The MANET connects with the cellular network via MANET gateways working at the network layer, which could be built within cellular base stations. The coverage of the gateway is much more than that of the cellular base station. The gateways receive wireless signals from the MANET, and transmit the contained information to the cellular base station. The gateway is also an authorizing center and an IP proxy. Though an all-IP network and IP mobility management is a general trend [6], it is not very necessary in this MANET due to the increased overheads and complexity. The MANET gateway only admits the authorized devices to access.

CNSS (Compass Navigation Satellite System, also called Beidou [7]) will provide not only positioning and clocking service for the mobile users and the standing stations, but

In order to implement mobile communications for vast remote rural and pastoral areas of Tibet, an integrated wireless communication system utilizing MANET for networking is proposed.

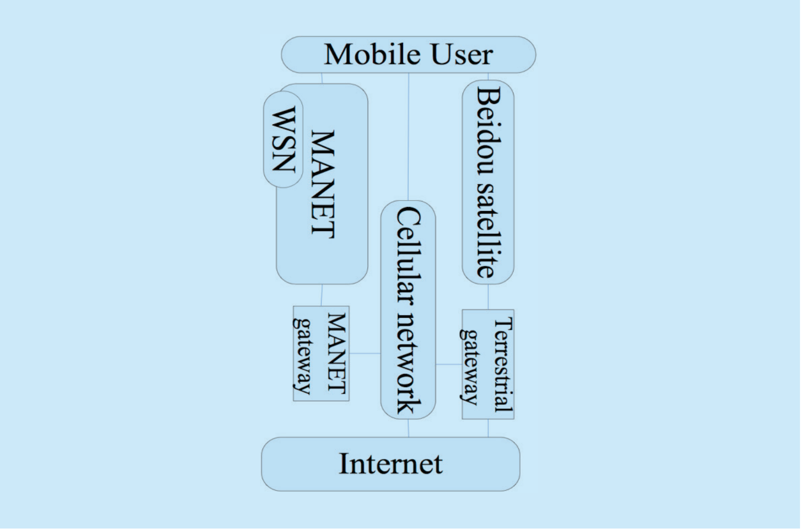

Fig.1 *Integrated wireless communication system*

also its peculiar message service that is much more inexpensive than other satellite communication services and can be used in emergency situations.

Considering that the vast area should be covered and the system is expected to be very energy-constraint, the system will just provide voice, message, and low-rate data services, while the proper frequency range will be around 300MHz or 450MHz-500MHz.The MAC should have two working modes similar to IEEE 802.11. When the mobile users can directly connect to one standing station, the AP mode is started and the standing station works as AP (Access Point). Otherwise, the Ad-hoc mode is preferred.

The common five layer protocol model can not adapt to the wireless mobile environment well [8]. For example, the current TCP implicitly assume that packet droppings are all come from congestions. But in this situation, packet droppings may caused by unstable wireless channels, which will make the TCP data rate much low and inefficiency. So the cross-layer method is expected for the system. To satisfy different QoS of different services, different network layer and physical layer solutions are provided. For voice service, the high priority at network layer makes latency lower and acceptable, and FEC (forward error correction) coding is used to reduce noise. Comparatively, for low rate data service, AQR (Automatic Repeat Request) decreases the bad influence of channel droppings to the TCP [9]. In Ref. [10], a cognitive radio-based multi-channel MAC protocol is proposed for Ad hoc networks, which is a good reference. The expected cross-layer routing protocol would interact with the cognitive radio layer and should base on energy control，position and hierarchy information [11][12].

Crosslayer method

Application layer	Voice	Low rate date
Transport layer	RTP/UDP	TCP
Network layer	High priority	Low priority
MAC layer	Dual- or multi-frequency-channel MAC	
Physical layer	Cognitive Radio (FEC)	Cognitive Radio (ARQ)

Fig.2 *Cross-layer structure for different services*

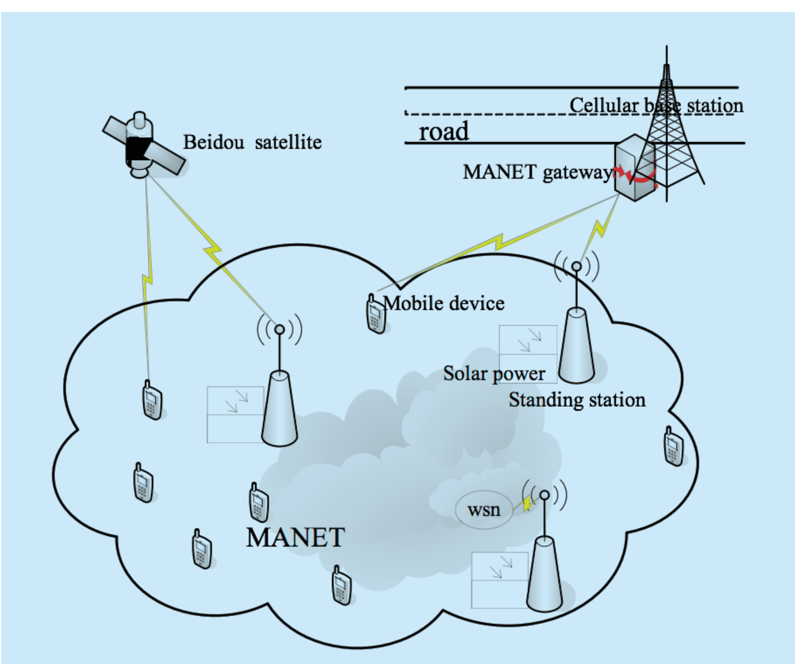

Fig.3 *MANET networking architecture*

III. Design and Maintenance of Network Topology

As showed in Fig.3, there are two types of nodes in the MANET. One is the standing station node; the other is the mobile user device node. The two types of nodes both participate in self-organizing network, but does not work as same as the common clustering Ad hoc network. The followings describe their characteristics and functions specifically.

2.1 The standing station

The standing stations are synthetic and have two functions in the system. When the few mobile user devices are so scarcely distributed that they can not network on their own, the standing stations help them to connect with each other and with the cellular gateway. In the other situation, when the mobile users can network by themselves, both the two kinds of nodes play different roles while networking. The stations will play a more important role on networking maintenance and routing arrangement. The management and the routing methods are expected to be based on energy control, position and hierarchy information[13][14]. In general, the stations will adapt data routing paths according to their energy status. To preserve nodes surviving is a priority.

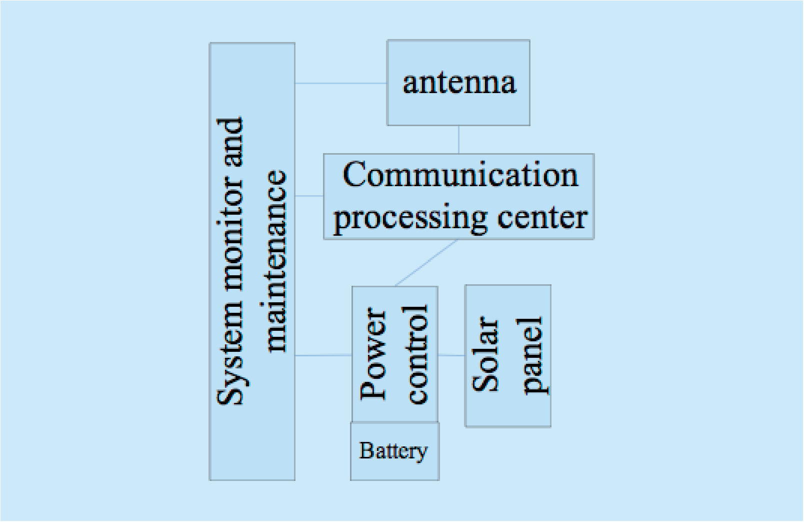

Fig.4 *Structure of standing station*

The standing station is supported mainly by solar energy and secondly by wind energy as shown in Fig.4, since Tibet is one of those distracts that have best solar energy. When the solar power is most powerful in summer, the station will be most used because it is the very season for nomadic herdsmen and all other kinds of activities. When it is becoming colder and colder, wind energy resource is becoming bigger and better. So snow weather and winter will not influence the system work if the wind energy equipments are integrated in the standing stations. Therefore, there is no need to install the too costly wired infrastructure. The stations have Beidou terminals for positioning and clocking. They are unwatched, and will be examined and maintained each summer as required.

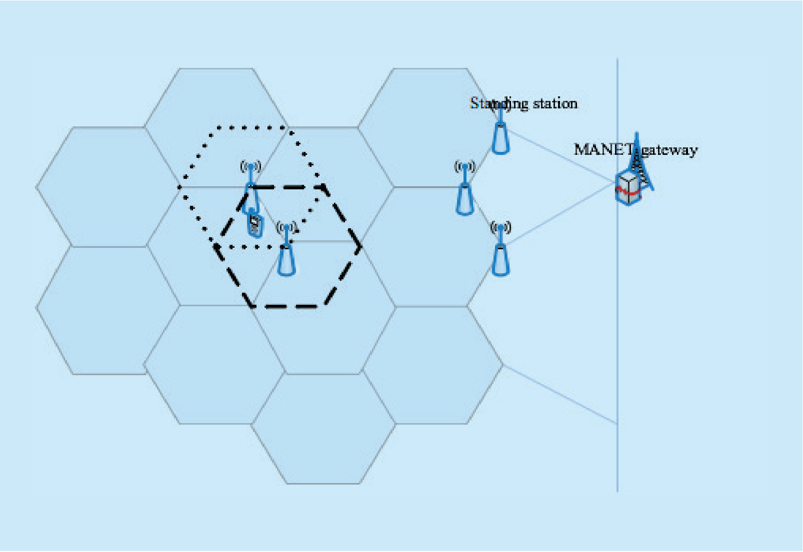

Fig.5 *Ideal topology of standing stations*

Different from the omni-directional antenna used by the mobile users' devices, three or four directional antennas will be equipped at the station. Due to these antennas and the solar energy, one station's signals can cover a much vast area.

The standing stations are supposed to inter-connect with each other. Fig.5 shows the ideal topology of the standing stations which makes each station connects with other three stations directly except the ones nearest to the MANET gateways. The coverage of the MANET gateway is much more than that of the cellular base station, and each gateway could connect with two or three the standing stations directly. The real topology will be some deformed of the ideal one according to the real topography, but the relation of connectivity just mentioned is unchanged, which makes sure that when one station losses connection with two stations, it will still in the station network. Furthermore, when several stations fail in operation, the station network will still be a connected graph in most cases. If one working standing station is totally isolated, it could act as a relay station for the

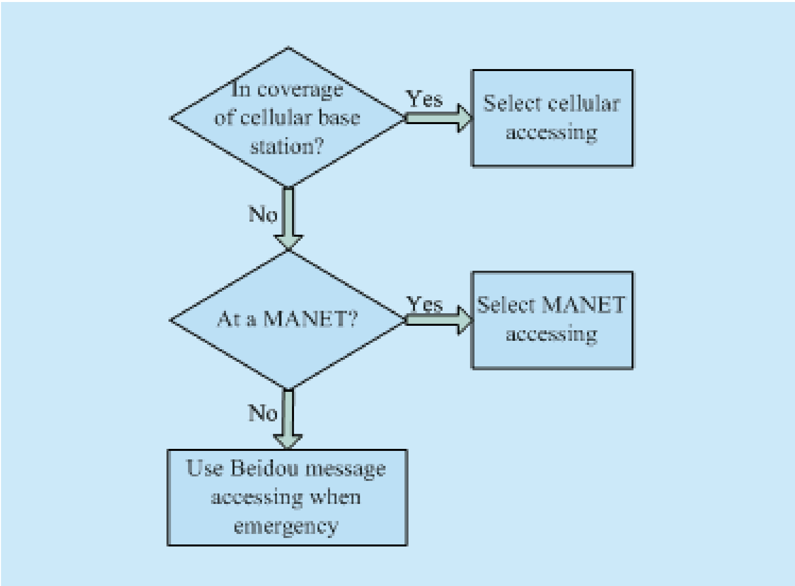

Fig.6 *Procedure of accessing selection for mobile user device*

covered mobile user devices.

On the other hand, each mobile user device is in the coverage of two standing stations as shown in Fig.5 using two dotted lines. The mobile user will be assigned to connect one according to the status of energy and busyness of the two standing stations. If one station is broken, there still exits one to connect. But if the two stations are broken simultaneously for one mobile user device, the mobile user device cannot connect one standing station directly. When one of its neighboring mobile user devices connects to another standing station, the mobile user device could connect with the standing station via this neighboring mobile user device.

In short, such a topology with redundancy is advantageous to networking maintenance and system robustness. If the standing station could be very self-surviving and steady working, the simpler topology is preferred.

Lastly, the standing station is much multi-functional. The standing station network with WSNs can do environmental sensing and deliver the sensing data back all the year, which is very important for Tibet environment research and protect. Also, the stations may be equipped with many other functions, such as being a power supplier of small electronic devices for passers-by, providing emergency phones, and so on.

2.2 The mobile user device

The mobile user device is multi-accessing-modes integrated. Three accessing modes are provided, respectively with cellular network, MANET and Beidou satellites.

Fig.6 shows the procedure on how the mobile user device does select an accessing.

Firstly, when it is under the coverage of the cellular base station, it can connect directly to the base station using the cellular access. To be noted that when a mobile user device is in the coverage of some cellular base station, it may also be in one MANET's coverage. In this situation, the mobile user device turns off the MANET accessing.

The secondary selection is the MANET access, which provides communications between MANET mobile users or with Internet through the gateways.

Lastly, the mobile user devices are also equipped with Beidou terminals. So, when some mobile users have emergency information and the other accessings can not be used, they can send messages through the Beidou message service.

IV. Routing Method and Energy Strategy

Routing method is to solve the problem of path selections from the sender to the destination. The current node determines the incoming data packet which adjacent node to transmit according to the routing table existing stored or instant calculated.

In the proposed MANET system, two different kinds of nodes, including the standing stations and the mobile user devices, work together. The standing stations internetwork according to the proposed topology as shown in Fig.5, and they store, update and exchange the information of the mobile user devices connected directly. In the connected graph of the working standing stations and the mobile user devices, the standing stations take responsible to do the routing calculation and distribute the proper routing table to each mobile user device.

The two kinds of nodes both equipped with Beidou positioning function, so the geographic topology of the established connected graph is easy to get and the distance of any two nodes can be calculated. The energy status of each node is self-measurable, and the mobile user devices send it to the connected standing station. The routing algorithm is based on the path distance, the hop number and the energy status of each nodes, and will adjust the routing pat, lower the data rate or shut low power nodes temporally to protect the low energy standing station and user devices for surviving. But because the user device can be turn off to reserve power for itself, the sustained working of the standing stations is the key of the networking maintenance.

The routing method and energy strategy is greatly simplified by the proposed topology, and is described below step by step:

- ◆ The standing stations exchange the information of their adjacent mobile user devices, and the complete topological map is formed rapidly and updated instantly.
- ◆ The routing table of each node is calculated using a weighted algorithm based on the path distance, the hop number and the energy status. And the mobile user devices get their routing table from the adjacent connected standing station.
- ◆ When the energy status of some standing station or mobile user device is not in optimal state, routing table are recalculated and updated.

In the simulation research, how the standing stations adjust routing tables using a weighted routing algorithm according to their energy status and its effect on energy consumption in a typical scenario is studied.

Simulation Analysis

In the simulation researches, the free and open source OMNeT++ (Objective Modular Network Testbed in C++) is used as the network simulator [9]. OMNeT++ is an object oriented discrete event network simulator, and is capable to do wireless communication network channel simulation, protocol simulation, simulation of the queue network, simulation of multi-processor and other distributed hardware systems, etc. OMNeT++ includes some embedded model, and the depth of the embedded model is infinite, which allows the user to draw the logical structure of the actual system in the simulation environment. The information, which each module could transmit, may contain any complicated data structure. Each module can directly send the information to the target point through the door or the line, or it can be transmitted through a pre route.

OMNeT++ is a network simulator with a double layer structure. In general, the topology of the network is written using NED, and the underlying modules are written using C++. The mapping from NED to C++ is realized by the network simulator. In the simulation of the research, we use NED to create the desired topological structure, and use C++ to implement the weighted routing algorithm.

In this routing algorithm, we take the shortest path Dijkstra algorithm as the basis, then multiply a weight W to the distance from the standing station to its adjacent nodes. For example, in the algorithm, to calculate one path from the mobile user device I to the other one J which passes through only two standing stations K and S, the distance formula of this path is $P(I,J)=D(I,K)+W_k*D(K,S)+W_s*D(S,J)$, in which W_k and W_s are the weight of the standing station K and S respectively. The different weights mean that the standing station is in different energy states.

The weight W=0 means that the standing station is in the best working condition, in which the energy consumed by a standing station can be replenished forthwith with its own energy production capacity. It is worth noting that the ‘be replenished forthwith’ here is a relative concept, and the working condition of one standing station is best as long as the speed of the energy supplement can meet its communication demands of the current time period. In other words, at this time, the energy consumption of processing and transmitting information packets of the standing station can be regarded as 0. Therefore, if the standing station is in the best working condition, the optimal path selection of the mobile user device is not needed to be calculated. If the distance between the mobile user device and its adjacent mobile user device is not less than the distance to its connected standing station, the optimal choice is to send the information packets to the connected standing station.

The weight W>0 means that the standing station does not work in the best state, and that the speed of energy replenished can not meet the all current communication demands of its adjacent mobile user devices. The bigger the W, the bigger the gap. The weight W=1 means that the standing station is regarded as the same as the mobile user device while doing routing calculations. The weight W>>1 means that the standing station does not allow themselves to be used as the intermediate node to transmit information packets.

The routing method based on the improved weighted Dijkstra algorithm is simulated and studied in the topology as shown in Fig.7. The

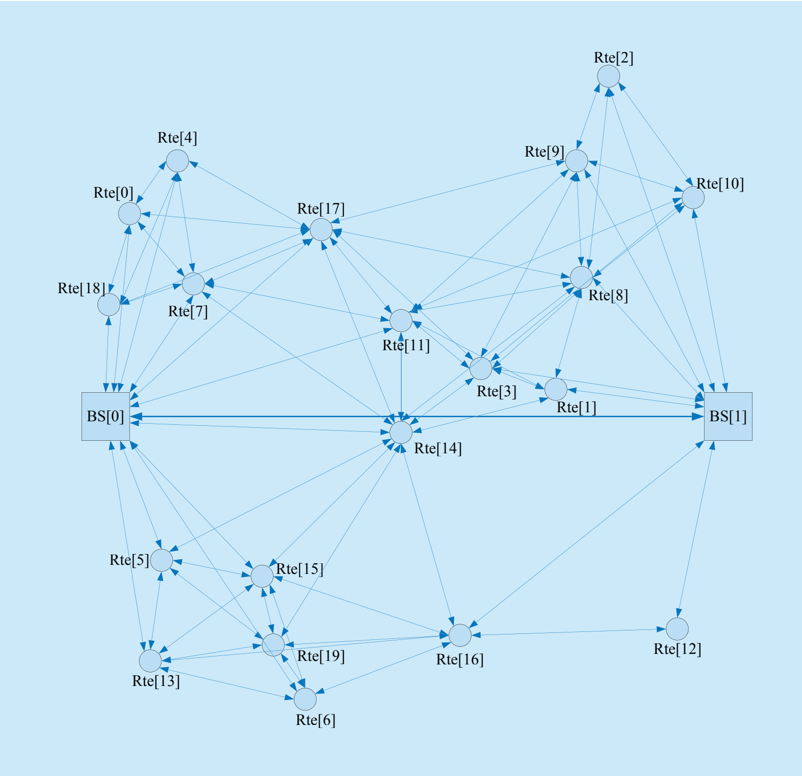

Fig.7 *Topology of simulation*

topology figure generated by OMNeT++ is not clear enough to be printed, so Fig.7 gives an illustrative drawing. The Net60 is (0, 0), and the right is the X axis, the down is the Y axis. BS[] is a standing station. BS[0] and BS[1] are set at (50, 300) and (450, 300) respectively, and connected to each other. Rte[] is a mobile user device, and the 20 mobile user devices are randomly distributed in the range of (0-500,0-600).When the distance between the Rte[]nodes is less than 200, they are connected to each other. In accordance with the requirements of the proposed topology, mobile user devices need to be connected with the nearest standing stations. So in the picture, the mobile user devices of the left side of the middle line (X=250) are all connected to BS[0], and the others are connected to BS[1]. The presented topology is a typical local scenario which needs to be faced practically.

Each node, including the BS[] node, is kept to send packets to Rte[16], Rte[17], and Rte[18] with a random time interval of exponential (0.5s). Rte[16], Rte[17], and Rte[18] are selected randomly. The size of the packet is fixed to 8192bits.The simulation time is 10s, during which a total of 784 packets are generated and sent. The quantity and the randomness of the information packets ensure the validity of the research on the total energy consumption.

Each node calculates its own energy consumption by processing and transmitting packets. The energy consumption is linearly correlated with the transmission distance and is needed to plus a constant initial energy. The consumption formula is: energy consumption = bits*10*0.000001*dist + bits*50.0*0.001.

Fig.8 shows the total energy consumed by the 2 standing stations and the 20 mobile user devices respectively by simulation according to the different weights took by the 2 standing stations simultaneously. When W=0, the energy consumption of the 20 mobile user devices is the least, and that of the 2 standing station is the most. But the energy consumed by the standing stations can be replenished forthwith, so it is the best state. When W=0.3, a few of information packets pass through less standing stations, and the total energy consumption of the mobile user devices is increasing. When W=1, more information packets pass through less standing stations, and the total energy consumption of the mobile user devices is also greatly increased. When W=10000, except for those packets generated and sent by the standing stations, the other packets all no longer pass through the standing stations, and the total energy consumption of the mobile user devices achieves maximum.

In the designed simulation, to adjust routing tables according to the change of the energy status of the mobile user node is not considered, but the application principle is the same. Considering the speed of energy replenished of the mobile user devices is more difficult and slow, so the actual system should limit the use of the mobile user device node as the transmission mediate node. For example, the mobile user device node is forbidden to transmit packets of the low priority data service and only to permit packets of the high priority voice service. Meanwhile, when the working state of a standing station is not at its best, the activity level of the adjacent connected mobile user devices should be reduced accordingly, or some of these adjacent mobile user devices should be arranged to transform to connect the other possible standing station.

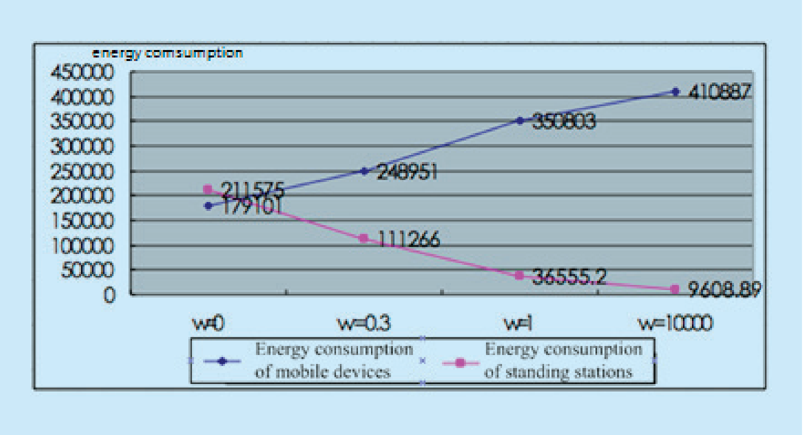

Fig.8 *Energy consumption of standing stations and mobiledevices*

V. Conclusion

In this paper, to realize mobile communications for vast remote rural and pastoral areas of Tibet, an integrated wireless communication system utilizing MANET for networking is proposed. The system can reduce the cost of network deployment, and provide voice, message and low rate data services to mobile users in order to meet the main communication demands.

The system consists of two types of nodes, which are the standing stations and the mobile user devices. The sparse mobile users, assisted with the solar-powered multi-functional standing stations mainly on networking maintenance and routing arrangement, self-organize into a MANET, which connects with the cellular network and Internet via the MANET gateway. Meanwhile, the mobile user devices have cellular accessing and Beidou message accessing to select for different situations, which makes sure that the mobile users get maximum communication guarantee.

The topology of the standing stations is designed, and the maintenance of networking is analyses specifically. The good designed topology greatly simplifies the routing method and energy strategy. In the simulation, we investigate how the standing stations adjust routing tables using the routing method with a improved weighted Dijkstra algorithm according to their energy status and the effect of the adjustment on energy consumption in a typical scenario. The results of the simulation show that the standing stations should to control the activity level or the connection of the adjacent connected mobile user devices according to the energy states of the standing stations and the adjacent mobile user devices. When the working state of a standing station is not at its best, the activity level of the adjacent connected mobile user devices should be reduced accordingly, or some of these adjacent mobile user devices should be arranged to transform to connect the other possible standing station.

In brief, the proposed integrated wireless communication system is feasible, and to realize the system needs to integrate communication, energy saving, solar energy utilization and other related technologies.

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References

[1] Report of the People's Government of the Tibet Autonomous Region on accelerating the development of the communications industry[R]. Tibet Government Report No. 37, 2011.

[2] KOBEL C, BALUJA G W, HABERMANN J.A survey on Wireless Mesh Network Applications in Rural Areas and Emerging Countries[C]// 2013IEEE Global Humanitarian Technology Conference, San Jose CA, 20-23 Oct. 2013:389 - 394.

[3] AKYILDIZ IF, WANG Xudong. ASurvey on Wireless Mesh Networks[J]. Communications Magazine, 2005, 43(9):23–30.

[4] DU Wencai, MA Zhengxin, BAI Yong et al. Integrated Wireless Networking Architecture for Maritime Communications[C]// 2010 11th ACIS International Conference on Software Engineering Artificial Intelligence Networking and Parallel/Distributed Computing, London, 9-11 June 2010: 134–138.

[5] Eslami M, Karimi O, Khodadadi T.A Survey on Wireless Mesh Networks: Architecture, Specifications and Challenges[C]//2014 IEEE 5th Control and System Graduate Research Colloquium, Shah Alam, 11-12 Aug. 2014:219 - 222.

[6] ABDULJALIL F M and BODHE S K.A Survey of Integrating IP Mobility Protocols and Mobile Ad hoc Networks[J].IEEE Communications Surveys & Tutorials, 2007, 9,(1): 14–30.

[7] http://www.beidou.gov.cn/ [OL], 2016.

[8] CHENG Hui, CAO Jiannong. A Design Framework and Taxonomy for Hybrid Routing Protocols in Mobile Ad Hoc Networks[J]. IEEE Communications Surveys & Tutorials, 2008, 10(3): 62–73.

[9] WEI Yunkai, MAO Yuming, LENG Supeng et al. A Low-Overhead Energy-Efficient ARQ Protocol for Wireless Sensor Networks[J]. China Communications, 2014,11(8):74-87.

[10] SU Hang, ZHANG Xi. Cognitive Radio Based Multi-Channel MAC Protocols for Wireless Ad Hoc networks[C]//IEEEGlobal Telecommunications Conference, 2007., Washington DC, 26-30 Nov. 2007:4857 - 4861.

[11] ZHAI Linbo, LIU Yuan-an. A Tree-based Cognitive Radio Routing Protocol in Ad Hoc Networks[J]. Journal of Beijing University of Posts and Telecommunications, 2012, 35(1): 85–89.

[12] BO Cheng, HAN Junze, LI Xiangyang et al. SA-MAC: Self-stabilizing Adaptive MAC Protocol for Wireless Sensor Networks[J]. Journal of Computer Science and Technology, 2014, 29(4):605-617.

[13] YU Yinpeng, PENG Yuhuai, LIU Yejun et al. Survivable Routing Protocol for Green Wireless Mesh Networks Based on Energy Efficiency[J]. China Communications, 2014,11(8):117-124.

[14] WANG Dongyang, WU Muqing, WANG Hengyou et al. Reclaiming the Efficiency of Opportunistic Routing in Wireless Muti-Hop Networks. [J]. China Communications, 2014,11(8):145-156.

[15] https://omnetpp.org/ [OL], 2016.

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