Hybrid Satellite-Aerial-Terrestrial Networks for Public Safety

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Abstract. Wireless communication technologies play an irreplaceable role to satisfy Public Protection and Disaster Relief (PPDR) operational needs in the emergency situations. The existing practical solutions for PPDR system mainly include the dedicated public safety network, the commercial LTE network and the mobile satellite system (MSS), which are all separately operated due to the lack of a unified arrangement. In this context, this paper proposes a novel solution framework for the large-scale emergency scenarios, which is called the Hybrid Satellite-Aerial-Terrestrial (HSAT) system. The proposed HSAT system considers the integration of terrestrial components and the satellite network, and also added the low altitude platform (LAP) as a complementary component. Moreover, some new technologies in LTE are also included in the system, aiming to support the increasingly data-intensive traffic. By combining the respective advantages of each network, the proposed HSAT system can potentially offer higher throughput, wider coverage and stronger robustness, which are all highly demanded in PPDR networks.

Keywords: Public safety · Mobile satellite system · Low altitude platform · LTE network

1 Introduction

An effective Public Protection and Disaster Relief (PPDR) system is crucial to a successful response to emergency and disaster situations. Unlike the traditional communications in cellular networks, the PPDR system has a mission-critical aspect and thus places some special requirements on the underlying radio technologies. For example, the PPDR system should be easy to deploy, highly reliable, relatively low in price and high capacity-coverage.

Currently, two terrestrial wireless communication networks are utilized for emergency communication, i.e. the commercial cellular network and the dedicated public safety network (e.g. TETRA, APCO25 or DMR) [1,2]. The dedicated network aims at providing immediate access to the network with guaranteed reliability while the cellular network (e.g. LTE) is used to provide

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some broadband data-centric services. In addition, as a complement to terrestrial mobile communication systems, the mobile satellite communication system (MSS) has proved to be a valuable gap filler in public safety networks, since it can provide services in the regions where terrestrial network collapses due to the disaster. Although MSS provides wider coverage and is more disaster tolerant, it usually requires the existence of Line of Sight (LOS) and endures longer transmission delay. Therefore, the integration of MSS and the terrestrial network becomes highly demanded. Moreover, during a large-scale natural disaster, the LTE base stations (BSs) could become overloaded or even totally destroyed. In these scenarios, the airborne communication systems have been recently studied for providing rapidly deployable and resilient accesses [3,4]. The aerial station is an air balloon or aircraft based low attitude platform (LAP), which can be built within one hour. It can not only play a role as the LTE base station, but also communicate with the satellite.

In this paper, we propose a solution framework for a large-scale PPDR network, which is called the Hybrid Satellite-Aerial-Terrestrial (HSAT) system. This system intelligently combines the satellite communication, the terrestrial network and the proposed LAP concept. Besides, some new technologies, such as the Device-to-Device (D2D) communication and cognitive radios (CR) will be added to the PPDR networks, in order to support the increasingly data-intensive traffic. Compared with the existing PPDR network, the proposed hybrid Satellite-Aerial-Terrestrial system could effectively combine the respective advantages of each network, and will provide a complete and feasible solution for the large-scale natural disasters.

The rest of the paper is organized as follows. In Sect. 2, we describe the existing terrestrial communication system, which mainly includes the dedicated public safety network and the LTE network. We also discuss the architecture of MSS for PPDR service provisioning. Then in Sect. 3, we will illustrate the basic architecture of the proposed HSAT system and discuss some critical challenges of the practical operation of the system. Finally, Sect. 4 concludes the paper.

2 Existing Public Safety Networks

2.1 Terrestrial Communication Networks

During a large-scale emergency or disaster, the public communication network may cease to work after suffering great damages. The dedicated public safety network for PPDR communication plays an essential role in the field first aid. Compared with the common mobile communication system, the dedicated network is devoted for special command and schedule. With the large-cell and low-density network organization, a base station can cover the range of tens of kilometers. If communication is interrupted in one region, a mobile station such as a vehicle station can continue to function for a certain area. The major feature of the dedicated network is that it can provide a rich set of voice-centric services, such as push-to-talk, group calling and emergency dispatching.

Nevertheless, with the prevalent of smart devices, the emergency information tends to be diversified, transferring from voice-centric to data-centric, the rescuing image or video information related geographic location is an example. Although some efforts have been made to improve the system capacity, the solution lags far behind the achievements of existing mobile networks. In addition, the commercial LTE system serves for ordinary users rather than only first responders. Thus, the adoption of commercial LTE technology for the PPDR community could meet common subscribers routine communications who are in the hard-hit area.

Although these two networks are operating separately from now on, some researches have been done to introduce the commercial LTE system to PPDR. The synergies between these two networks are obvious, which includes maximization of the economies of scale, better capacity, enhanced resiliency and improved radio coverage. Based on the above considerations, the integration of dedicated public safety network and LTE systems is irresistible future tendency.

2.2 Mobile Satellite Communication Networks

Based on the space platform (e.g. geostationary satellite, middle/low orbit satellite), satellite communication system is used for real-time acquisition, transmission and process of the spatial information. Due to the advantages of high disaster tolerance, large coverage and flexible network organization, the satellite communication system can communicate directly with the disaster acquisition system, the rescue command system and the disaster broadcasting system through vehicle or aircraft stations.

Satellite communication services can be categorized as fixed satellite services (e.g. satellite TV services) and mobile satellite services. The mobile satellite services are widely used in the marine, aviation, remote areas as well as disaster or emergency situations. During a disaster, satellite-based phone can communicate directly with the satellite system when the LOS is satisfied. Otherwise, the emergency communication vehicles or aircrafts would serve as a simple repeater that fills the NLOS holes. In this case, the vehicle or aircraft stations can retransmit the received signal at the frequency same as the satellite or not. As shown in Fig. 1, the satellite-based public safety network infrastructure consists of not only the satellite but also the vehicle/aircraft station. In fact, the introducing of the vehicle/aircraft station could bring many benefits, including filling the gaps in satellite coverage, enhancing the satellite capacity and improving the successful access probability.

So far, the network protocol of satellite system is developing from PPP, ATM to IP technology over satellite, aiming to connect with the terrestrial interoperability. Meanwhile, satellite service is also converting from a single service to integration with telecommunication and the internet. Thus, to meet the users massive and diversified multimedia requirements, the broadband and IP-based architecture becomes an irresistible trend.

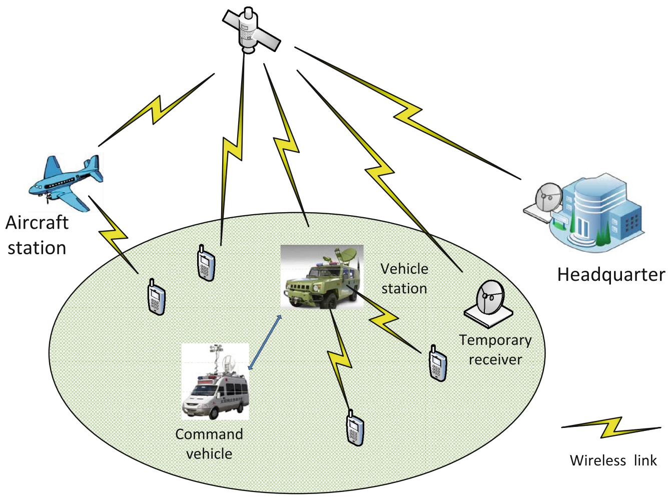

Fig. 1. The satellite-based public safety network infrastructure

2.3 Comparison of MSS and Terrestrial Networks

The above two subsections presented the basic characteristics of the terrestrial and satellite network respectively. In this subsection, we focus on the comparison of the two networks, so as to provide a clear direction for the design of system architecture. A brief outline of the comparison is shown in Table 1.

Table 1. Comparison of satellite and terrestrial systems

	Advantages	Disadvantages
Satellite	large coverage	require LOS transmission
	less impacted by disaster	long delay
		limited onboard power
Terrestrial	enhanced capacity	susceptible to disaster
	diversified multimedia services	

MSS could provide wider coverage and is more disaster tolerant. However, some limitations of satellite communications should not be ignored. For example, the satellite communication requires the existence of LOS so that users in shadowing or indoor areas cannot be covered effectively. Moreover, the satellite communication endures long transmission delay [5], which makes the dynamic resource allocation and Adaptive Modulation and Coding (AMC) no longer effective in satellite communication system. Other limitations may include the high cost and the incompatibility with LTE networks. On the other hand, the

LTE-based terrestrial system could provide low cost coverage for high-density populations. It also has higher spectrum efficiency and could satisfy a wide range of data communication needs in emergency scenarios.

3 Hybrid Satellite-Aerial-Terrestrial Network

3.1 Architecture of Hybrid Network

As described above, satellite system is characterized by large coverage and less impacted by disaster, while terrestrial communication network is featured as enhanced capacity and supportability of diversified multimedia services. Therefore, the integration of these two networks can bring significant benefits. Within the terrestrial networks, the adoption of commercial mainstream LTE technology to deal with the increasingly data-intensive applications is widely agreed within the PPDR community. Some promising technologies that could be useful in PPDR networks are described as follows.

1. All-IP system architecture and flexible air interface
   The LTE IP connectivity services are implemented by the Evolved Packet Core (EPC), which is the fundamental part of an LTE network. Within the EPC, the LTE could also offer different levels of interoperability provide a wide range of multimedia services and guarantee prioritized handling of emergency calls. The air interface supports flexible carrier bandwidths from below 5 MHz up to 20 MHz, which can satisfy different end-to-end QoS for different users.
2. D2D (Device-to-Device) Technology
   D2D communication allows adjacent devices within or outside of cellular coverage to communicate directly instead of relaying by the BS. It can largely offload the burden of BS, especially when only few BSs survived in the emergency situation [1]. Besides, the D2D communication has the potential to save the transmission power of terminals, which significantly enlarges the network lifetime in emergency scenarios.
3. CRs (Cognitive Radios)
   CR technology is expected to detect the spectrum hole and use the unoccupied spectrum opportunistically, thus improving the spectrum efficiency. It can also sense users needs through learning algorithm and allocate just enough radio resources for them [6]. Another aspect of CR is to develop applications that can locate, communicate and reach the victims who are stuck in disaster areas or behind obstacles.

Although the LTE network has great potential in broadband data service provisions, it is highly possible that most of the LTE BSs become damaged or even cease to work due to the severe natural disaster. In this case, the utilization of LAP as an alternative to the terrestrial BS will become necessary. Based on the above considerations, the complete architecture of our proposed HSAT system is shown in Fig. 2. As we can see, the HSAT system comprises three main parts:

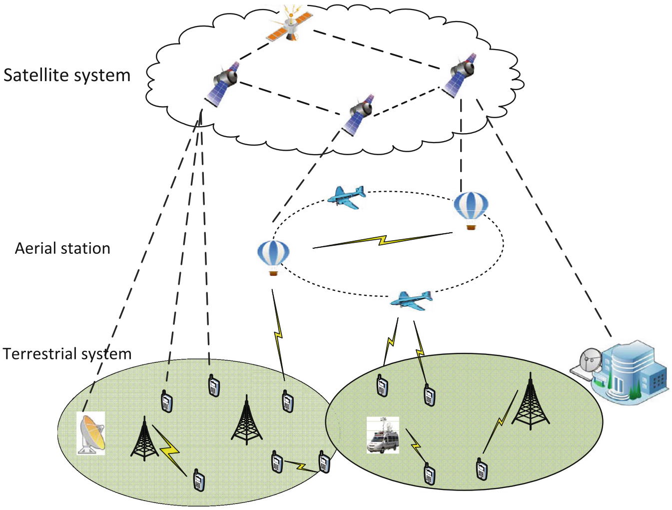

Fig. 2. The HSAT network architecture

the MSS, air balloon or aircraft based aerial station and the survived terrestrial network. The aerial station can be fast built and fill the gaps of destroyed LTE base station. It is generally about 100–1000 m high, lifting with a low-complexity LTE-A eNB, named Aerial eNodeB (AeNB). It is worth mentioning that the AeNB is expected to communicate with satellite as well as terrestrial users that within its coverage area.

In case of a large-scale natural disaster, some mobile BSs along with the public safety personnel will be sent to the incident areas. Such dedicated public safety network is specifically useful in providing robust and low-delayed services for the first responders. Meanwhile, the stationary LTE BSs are used to deal with the routine data traffic. Some new technologies, such as the Device-to-Device (D2D) communication and cognitive radios (CR) could also be added to the LTE network, in order to support the increasingly data-intensive traffic. In addition, we apply the LAP in the proposed architecture as an effective alternative to the terrestrial BSs, in case that the terrestrial BSs collapse and cease to work due to the disaster. Finally, as for the areas that are out of terrestrial coverage, the MSS could be utilized to provide seamless services for both the victims and first responders.

3.2 Integration Challenges

Although it is of significant benefits to simultaneously utilize the terrestrial and satellite network in the PPDR system, how to integrate the two networks effectively still faces some practical challenges. From the technical perspective, the major challenges may include the transparent handover issues, interpretability and resource allocation [7].

1. Transparent Handover
   In the hybrid satellite-terrestrial system, two kinds of handovers should be considered, i.e. the inter-beam handover and the handover between the satellite and terrestrial cells. Since the low earth orbit (LEO) satellites are non-geostationary, there may be continuous handovers among satellites even for fixed users. For the satellite-terrestrial handover, several new access technologies, such as the D2D communication could also be utilized, which makes the handover process more complex. Moreover, the handover is expected to be transparent from the users perspective. In another words, user ends are able to choose an access network according to the link state adaptively. For the sake of transparency, terminals are required multimode transmission and supports low latency seamless handover between different systems, which is much challenging for hardware chip design and handover algorithms [8].
2. Interoperability
   Satellite and territorial system both have their own architectures catering for their respectively independent features. Among the major challenges facing the integration is the problem of interoperability. As described above, in order to fulfill diversified public communication services, both of the two networks are developing towards broadband and IP. Meanwhile, IP protocol is so successfully used in the internet. Thus, constructing the integrated PPDR over IP is the future trend.
3. Resource Allocation
   There are some differences between the satellite and terrestrial communication systems, such as the standards, the forms of physical resource, frequency bands as well as the transmit power, coverage, capacity and control plane overhead, etc. Therefore, it is critical for the integrated system to utilize the limited radio resources effectively and efficiently. The resource allocation problem mainly consists of spectrum management and power control. Spectrum management: The satellite systems generally use s-band (2–4 GHZ) for direct communication with users, and Ka-band (27–40 GHZ) for feedback to the satellite receiver. The terrestrial system uses 900 MHz and 1800 MHz. Possibly, there still exists frequency overlapping. A series of measures should be used for efficient spectrum management, such as rational planning [8] interference avoiding or suppression [9] cognitive radio technology [10], etc. Power control: Due to the limited carrying capacity, the LAP is usually unable to carry enough battery, which is also true with the space based satellites. However, it is convenient for the ground based LTE BS to supply power. Therefore, different transmit power characters should be taken into consideration for extending the network effective lifetime.

4 Conclusion

The LTE-based terrestrial communication network has enhanced capacity and is expected to offer diversified multimedia services in an emergency situation. The satellite communication network could provide wider coverage and suffer less from the disaster. Therefore, the integration of these two networks could bring synergic gain. In this paper, we propose the HSAT system for PPDR networks, which combines the satellite communication, the terrestrial network and the proposed LAP concept. Besides, some new technologies, such as D2D and CR are added to the hybrid system. The proposed HSAT system can potentially offer higher throughput, wider coverage and stronger robustness, which is promising to be used in the PPDR networks.

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References

1. Doumi, T., Dolan, M.F., Tatesh, S., Casati, A., Tsirtsis, G., Anchan, K., Flore, D.: LTE for public safety networks. IEEE Commun. Mag. **51**(2), 106–112 (2013)
2. Ferrs, R., Sallent, O., Baldini, G., Goratti, L.: LTE: the technology driver for future public safety communications. IEEE Commun. Mag. **51**(10), 154–161 (2013)
3. Bucaille, I., Hethuin, S., Munari, A., Hermenier, R., Rasheed, T., Allsopp, S.: Rapidly deployable network for tactical applications: aerial base station with opportunistic links for unattended and temporary events absolute example. In: Military Communications Conference, MILCOM 2013, pp. 1116–1120. IEEE Press (2013)
4. Gomez, K., Rasheed, T., Reynaud, L., Bucaille, I.: Realistic deployments of LTE-based hybrid aerial-terrestrial networks for public safety. In: IEEE 18th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), pp. 233–237 (2013)
5. Siyang, L., Fei, Q., Zhen, G., Yuan, Z., Yizhou, H.: LTE-satellite: chinese proposal for satellite component of IMT-advanced system. China Commun. **10**(10), 47–64 (2013)
6. Al-Hourani, A., Kandeepan, S.: Temporary cognitive femtocell network for public safety LTE. In: 2013 IEEE 18th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), pp. 190–195 (2013)
7. Yang, L., Zhang, Y., Li, X., Gao, X.: Radio resource allocation for wideband GEO satellite mobile communication system. In: International Conference on Wireless Communications and Signal Processing (WCSP), pp. 1–5 (2013)
8. Sadek, M., Aissa, S.: Personal satellite communication: technologies and challenges. IEEE Wirel. Commun. **19**(6), 28–35 (2012)
9. Deslandes, V., Tronc, J., Beylot, A.-L.: Analysis of interference issues in integrated satellite and terrestrial mobile systems. In: 2010 5th Advanced Satellite Multimedia Systems Conference (ASMA) and the 11th Signal Processing for Space Communications Workshop (SPSC), pp. 256–261. IEEE Press (2010)
10. Sharma, S.K., Chatzinotas, S., Ottersten, B.: Cognitive radio techniques for satellite communication systems. In: Vehicular Technology Conference (VTC Fall), pp. 1–5. IEEE Press (2013)