Applications of Recent Wireless Standards in Satellite Networking

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Abstract:

Recent developments and research in the aerospace industry have lead to an increased adoption of recent wireless standards in building satellite networks. These standards include ZigBee and Bluetooth for intra-satellite networking and Wi-Fi and WiMAX for inter-satellite networking.

Keywords

Satellite, Networking, Fractionation, Mobile, Survey, ZigBee, Bluetooth, WiMAX, Wi-Fi

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Description

A survey paper discussing applications of recent wireless standards in satellite networking.

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1. Indroduction

For many years, the primary focus of satellite networking has been improving the speed of data transfer between the ground station and the satellite. This has

led to a focus on long distance, high data rate protocols. Recent satellite research and technological improvements have brought the problems faced by satellite networks closer their counterparts on the ground. Many researchers are now applying standards used terrestrially to the networks in space.

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2. Background

Satellites have traditionally been very expensive to design, build, launch and maintain. Costs have driven development of satellites to be smaller and less complex. Smaller satellites are cheaper, and simpler satellites are less likely to fail [Bearden01].

2.1 Components

A satellite network is built from two major components: earth stations and satellites. The earth station can be a fixed or mobile station on Earth. Generally the focus of satellite networking has been on the wireless link between these two components. In the 90s, inter-satellite links began to appear in certain satellite constellations. More recently, sensors and subsystems have extended the focus satellite wireless networking to short range wireless protocols [Hersovici06]. And, interest in separating system tasks to increase overall network and system survivability and versatility [Brown06] have pushed development of more advanced inter-satellite networks.

2.2 Network Types

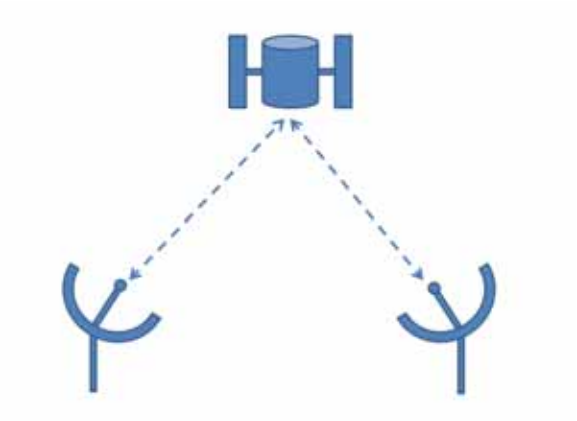

Figure 1. "Bent-Pipe" Architecture

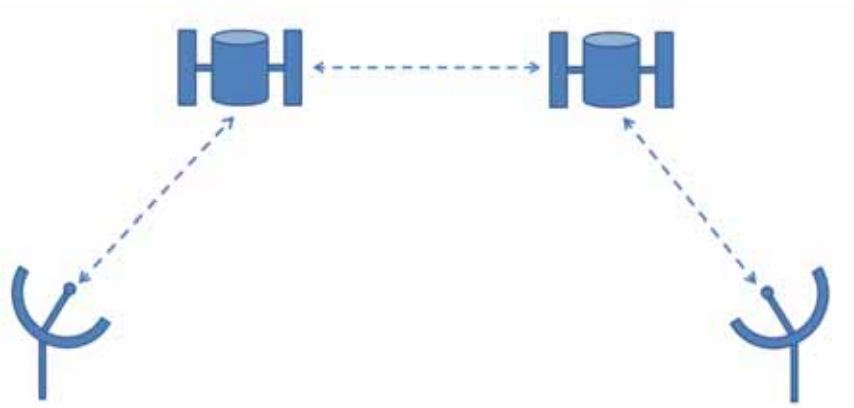

Figure 2. Space-Based Satellite Network

There are two main satellite network types: ground-based, Figure 1, and space-based, Figure 2 [Floreani05]. Both configurations have benefits. Space-based networks reduce the radio traffic on the ground by reducing the number of transmissions between ground and space because they eliminate the need to have contact with multiple satellites simultaneously from the ground [Wood01]. Ground-based networks on the other hand, greatly simplify the systems onboard the satellites and are often reusable for other purposes [Wood01].

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3. Applications

Current applications of satellite wireless networking are focusing on providing voice and data connectivity across the globe. Many systems are using inter-satellite links while some continue to use the "bent-pipe" architecture.

3.1 Inter-Satellite Networking

Early attempts at inter-satellite networking have demonstrated the feasibility and benefits of using satellite to satellite communication in satellite networks. More recent developments have focused on adapting off-the-shelf technologies for use in satellite networks.

3.1.1. Iridium

The Iridium satellite constellation is probably the most well known satellite constellation using inter-satellite networking. The constellation provides satellite based phone service across the world. Iridium's inter-satellite network link uses several wireless technologies including Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Quadrature phase-shift keying (QPSK). The link frequencies are between 13.18 and 13.38 GHz. Iridium's use of inter-satellite networking allows many phone calls to be routed directly between satellites instead of having to traverse several ground based repeaters, thus cutting the cost of the phone call.

3.1.2. Cisco Router in Low Earth Orbit

The Cisco Router in Low Earth Orbit (CLEO) refers to a project where a Cisco 3521 mobile access router was put on a satellite to verify that a commercial-off-the-shelf (COTS) router could work in space. Since its launch in 2002 and subsequent demonstration that COTS networking technologies with minor modifications could be utilized for satellites, it has continued to contribute to further research in satellite networking. Most recently, CLEO demonstrated the successful use of IPv6 and IPSec on satellites [Wood07]. The success of this project has led to further expansion of the use of COTS networking technologies in projects like Internet Routing in Space (IRIS). The success of the CLEO project demonstrates the feasibility of putting complex networking hardware on satellites to perform the complex routing calculations required by inter-satellite links.

3.1 "Bent-Pipe" Networking

While inter-satellite networking continues to make headway, the traditional "bent-pipe" architecture remains a strong contender and is still being put into use into many new networking systems.

3.2.1. Internet on Airplanes

One recently developed application of the "bent-pipe" architecture is providing internet to airplanes. As airlines continue to strive to provide more comfortable flights with more useful services, in-flight Internet is a logical next step. There are many benefits achieved by connecting airplanes to the Internet. The most obvious is online entertainment and work; the Internet would allow people to continue their usual online activities in-flight. Additionally, the airplane could be provided with TV movies for use by the passengers. Beyond these benefits it would provide for medical consultations and transfer of vital health information between doctors on the ground and the airplane. In the event of an emergency data recorded during the flight and stored safely elsewhere could be invaluable in figuring out what happened. And to prevent problems, maintenance data can be transferred to catch potential problems before they happen. [Werner]

There are several competing networks that provide or attempted to provide this service. All of the services use the "bent-pipe" architecture, using ground stations located in various parts of the world to send and receive data to and from airplanes. Of the networks, Inmarsat and SITA's Satellite Aircom are the most popular that continue to provide service. A major roadblock to the success of such systems is the airlines avoiding the added cost and weight for each airplane using the system. [Werner]

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4. Research

Recent trends in research in spacecraft design and control are pushing the boundaries of satellite wireless networking. In order to reduce the weight of a satellite and subsequently the cost of launch, subsystems and sensors are beginning to be connected with wireless links instead of cables. Additionally, an increased focus on modularity is leading to satellites being divided into smaller functional units and networked wirelessly. Finally, research into making satellites behave as a group is requiring the use of inter-satellite wireless networks.

4.1 Intra-Satellite Networking

One new area of applying wireless networking in satellites is intra-satellite communication. A satellite is comprised of many different subsystems and sensors. In traditional construction, each subsystem is networked with the others, and sensors are connected with their respective subsystems over wired interfaces. Recently, however, the concept of using off the shelf wireless motes to replace the wiring has been evaluated [Vladimirova07]. Protocols used for Wireless Personal Area Networks (WPANs) and wireless sensor networks are most suited for this task.

4.1.1. WPAN

ZigBee is a protocol based on IEEE standard 802.15.4. It is designed to be low-cost and low-power. The expected data rate in mesh mode is comparable to the popular controller area network (CAN) standard. ZigBee supports Mesh, point-to-multipoint and cluster tree configurations [Herscovici06]. The versatility of ZigBee provides an attractive option when choosing a protocol for communications on the satellite. Additionally, ZigBee has seen extensive use terrestrially in sensor acquisition and control.

Bluetooth is a protocol based on IEEE standard 802.15.1. It has a slightly smaller range, but, it has a higher data rate, uses more power, and only supports Ad-hoc configuration [Herscovici06]. Bluetooth's higher data bandwidth would allow more data to be transferred, but its higher power use is often and unwelcome tradeoff.

4.2. Inter-Satellite Networking

Traditionally, most applications of satellite networking have consisted of a satellite relaying data between two ground stations. Recent research into fractionation and formation flying prevent the use of the traditional "bent-pipe" architecture. These concepts in addition a desire to reduce development costs are prompting satellite developers to look towards COTS technologies for their applications. The distances involved in these systems often prevent the use of protocols like ZigBee or Bluetooth. So, designers have turned to longer range protocols such as Wi-Fi and WiMAX.

4.2.1. Fractionation

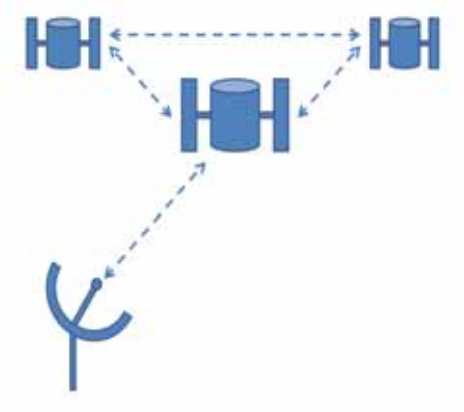

Figure 2. Fractionated Spacecraft

Fractionated satellites are satellite systems that have had components and subsystem tasks modularized and divided into separate spacecrafts, shown in Figure 3. These modular systems are easier to design and replace. By separating the functions of a single system in multiple satellites, each satellite becomes simpler and thus, more reliable. If a particular piece of the system is lost then another satellite can take it over or be launched quickly to restore functionality.

4.2.2. Formation Flying

Recent interest in satellite systems that maneuver as a group requires the satellites to communicate directly with each other. The delays involved in transmitting information to the ground for processing are too great to allow for proper maneuvering. Depending on the distances between the satellites and the amount of data that needs to be transferred ZigBee may still be used. However, if the distances exceed 100 m or the data rate exceeds 250 kbps than Wi-Fi or WiMAX is a better choice.

4.2.3. Wi-Fi

The Wi-Fi protocols are based on the IEEE standards 802.11 a/b/g/n. Wi-Fi a, b, and g can transmit up to 100 m at 11-54 Mbps and supports point-to-multipoint and ad-hoc configuration [Herscovici06]. 802.11n increases the data rate to 248 Mbps and the range to 250 m. Wi-Fi would be useful for close range formation flying, but would not be appropriate for many of the large distances found in satellite networks.

4.2.4. WiMAX

WiMAX is based on IEEE standard 802.16. WiMAX can transmit up to 50 km at 280 Mbps and supports point-to-multipoint and mesh configurations [Herscovici06]. WiMAX's long range and high data rate make it a very suitable option for use in satellite networking.

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5. Summary

Satellite networking has traditionally been a field dominated by the "bent-pipe" architecture. However, recently, applications and research have necessitated a shift towards adding inter-satellite networking. Additionally, new concepts in spacecraft design are extending the wireless boundary to within the satellite itself. The driving factors behind these changes in thought are cost and reliability, which also are driving designs using COTS technologies. These trends will likely continue as even more effort is spent to make satellite networks cheap and reliable.

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List of Acronyms

- CAN: Controller Area Network
- CLEO: Cisco Router in Low Earth Orbit
- COTS: Commercial-off-the-shelf
- FDMA: Frequency Division Multiple Access
- IEEE: Institute of Electrical and Electronics Engineers
- IP: Internet Protocol
- IRIS: Internet Routing in Space
- QPSK: Quadrature phase-shift keying
- TDMA: Time Division Multiple Access
- Wi-Fi: Wireless Fidelity
- WiMAX: Worldwide Interoperability for Microwave Access
- WPAN: Wireless Personal Area Network

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