Poster Abstract: Satellite Based Wireless Sensor Networks – Global Scale Sensing with Nano- and Pico-Satellites

Walter Colitti
Vrije Universiteit Brussel
ETRO Dept.
Pleinlaan 2, B-1050
Brussels, Belgium
+32 2 629 29 06
wcolitti@etro.vub.ac.be

Kris Steenhaut
Vrije Universiteit Brussel
EhB/IWT
Pleinlaan 2, B-1050
Brussels, Belgium
+32 2 629 29 76
ksteenha@etro.vub.ac.be

Nicolas Descouvemont
Space Applications Services
Leuvensesteenweg 325,
B-1932
Zaventem, Belgium
+32 2 721 54 84
nd@spaceapplications.com

Adam Dunkels
Swedish Institute of
Computer Science
Isafjordsgatan 22 16440
Kista, Sweden
+46 8 633 16 14
adam@sics.se

ABSTRACT
Space and Earth monitoring is the next step for sensor networks. Distributed systems of small sensor-equipped satellites improve the cost efficiency and the missions' performance. This abstract discusses the characteristics of satellite Wireless Sensor Networks (WSNs) and the challenges they introduce.

Categories and Subject Descriptors
C.2.4 [**Computer-Communication Networks**]: Distributed Systems – *Distributed applications.*

General Terms
Algorithms, Management, Design.

Keywords
Satellite sensor networks, Earth Observation, inter-satellite communication, nano- pico-satellite.

1. INTRODUCTION
Traditional satellite missions are extremely expensive to design, build, launch and operate. Because of the high cost, the aerospace industry have started directing its attention to missions consisting of many, distributed, small and inexpensive satellites. Distributed space missions consist of multiple satellites working in a coordinated fashion to execute the mission's common goal [2].

Earth Observation (EO) is one of the main focuses of both the industry and the research community. EO missions consist of a group of nano-satellites, small satellites with a mass of a few kilograms, or pico-satellites, with a mass of less than one kilogram, flying in formation or forming a constellation [2]. Figure 1 illustrates an example of a satellite sensor network.

Satellite sensor missions pose a set of new challenges for the sensor network community in terms of reliability, communication and routing. In this abstract, we discuss the similarities and differences between terrestrial and satellite-based sensor networks.

SenSys'08, November 5–7, 2008, Raleigh, North Carolina, USA.
ACM 978-1-59593-990-6/08/11

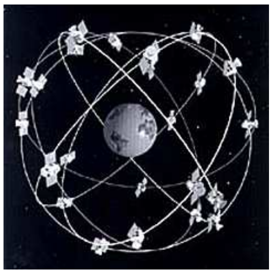

Figure 1. Satellite sensor network

2. APPLICATIONS
We envision satellite sensor networks in Low Earth Orbit (LEO) to be the preferred technology for a variety of EO missions such as environment and agriculture studying, hazard and disaster monitoring, and observation for security and crisis management. Typical examples of environment monitoring are pollution, land, ocean surface and crop condition monitoring. Examples of hazard and disaster monitoring are flood prediction, earthquake, and urban disaster prediction. Example of security and crisis management are border, vehicle and activity watching.

Distributed satellite missions use one of the following satellite arrangements: Formation Flying or constellation. The aim of an FF is to create a virtual satellite, composed by the different elements of the formation. An FF formation can be used as an interferometer. The interferometry technique uses different images acquired from a slightly different point of view to correlate them in order to get a better resolution. With this method, the spatial resolution depends on the length of the baseline, which can grow to thousands of kilometers. This is impossible to realize with a single instrument.

In a constellation, the satellites are scattered around the Earth, achieving a quasi-instantaneous global coverage. Typical applications of a constellation mission are Earth positioning, telecommunication or Earth monitoring.

3. SATELLITE SENSOR NETWORKS
Satellite based sensor networks share many of the characteristics of terrestrial sensor networks, the primary one being the resource constraints. However, they also introduce new challenges mainly related to inter-satellite communication and routing. These similarities and challenges are described in this Section.

3.1 Similarities with terrestrial WSNs

Due to their small size, the nodes in a satellite sensor network have a limited amount of resources. This implies that, similarly to terrestrial sensor networks, the power consumption optimization is a major issue in the node design. This similarity facilitates the portability of terrestrial sensor's resource-constrained hardware and software to nano- and pico-satellites. The pico-satellites designed by Pumpkin Inc, for example, mount the MSP430 CPU which is typical of terrestrial sensor network hardware such as the Tmote Sky. Moreover, the pico-satellites from Pumpkin Inc use the µIP embedded TCP/IP stack [1, 3].

Along with the node architecture, the network architecture is another similarity that originates from the resource constraints. Nano- and pico-satellites may not have sufficient power to exchange data with the ground station on an individual basis. One possible solution to overcome power consumption problems consists in grouping the satellites in a cluster. One master satellite (i.e. the sink) is responsible for the communication with the ground station and various slave satellites transmit to the sink. This implies that routing is executed at different levels.

3.2 Challenges

3.2.1 Inter Satellite Link (ISL)

The ISL allows the satellites to exchange information and share resources to achieve the performance goal while reducing the traffic load to ground. In order to reduce the ISL cost and design time, the ongoing research is testing the suitability of commercial-off-the-shelf (COTS) communication protocols [2]. Specifically, the IEEE 802.11 (WiFi) and IEEE 802.16 (WiMax) standards are being investigated. The criteria for the selection of these two communication protocols are based on the range (i.e. higher propagation delays may be experienced in satellite communications), networking features (especially MAC functions to reduce the number of collisions) and the support for mobility. In addition, IP based technologies simplify the inter-networking with other future space networks. Preliminary results have already demonstrated that both WiMax and WiFi are promising candidates for the implementation of ISL. On one hand, the WiMax technology offers an extensive support for QoS, full native IP support and high physical layer efficiency. On the other hand, WiFi is a more mature technology and therefore may result in simpler portability to the space domain, on condition that the timing is adapted due to the higher propagation delays. A solution can be the combination of both technologies: WiFi for close proximity in formation flying missions while the long range of the WiMax protocol covers the connectivity in constellations.

3.2.2 Time synchronization and power saving

The non-zero propagation delay of satellite WSNs could impose challenges on time synchronization protocols and on the choice of the MAC protocol. In fact, the power saving mechanisms of various MAC protocols used in terrestrial WSNs rely on the time synchronization that dictates the moments in which the nodes communicate.

3.2.3 Routing

A common practice used in terrestrial sensor network applications is to design routing algorithms that minimize the communication power and consequently increase the sensor lifetime. This requirement needs to be ported to space applications and therefore the Friis free space propagation model needs to be taken into account. This model defines the relationship between the received and transmitted power and states that the communication power is significantly reduced when the information is transmitted from source to destination via multi-hop paths. However, distributed satellite missions impose strict time constraints, especially in a formation where the satellites need to maintain themselves in a precise relative position and orientation. Typical wireless real-time control systems have an upper bound of 10 ms for the end-to-end latency (including sensing, communication, computation and actuation). This implies constraints on the multi-hopping because the signal end-to-end delay depends on the number of traversed satellites (processing, queuing, and propagation delay).

3.2.4 Reliability

Similarly to terrestrial sensor networks, a satellite based sensor network is a distributed and unattended system. This implies that it needs to be dynamic and self-adaptive in order to react with network reconfigurations in case of failure. However, satellite sensor networks have to commit more challenging requirements as a consequence of the node mobility. Orbital velocity in LEO is approximately 7.5 Km/s and undesirable perturbations change the orbit over time. In addition, formation flying requires the nodes to keep a precise relative position and orientation, which causes more frequent reconfigurations in populated orbits.

4. CONCLUSIONS

New challenges arise as sensor networks move towards low-cost, nano- and pico-satellite missions in low-earth orbit. Although nano- and pico-satellite missions share the resource constraints and reliability requirements of terrestrial sensor networks, the long communication ranges, high-speed node mobility, and non-zero propagation delays requires us to revisit the underlying assumptions in network time synchronization, communication protocols, and power-saving mechanisms.

5. ACKNOWLEDGMENTS

This work has been done in the scope of the ITEA project European Sensor Network Architecture (ESNA) thanks to the support of IWT-Flanders.

6. REFERENCES

[1] Dunkels, A. *Full TCP/IPfor 8-Bit Architectures.* Proc. of the First International Conference on mobile applications, systems and services, 5-8 May 2003, San Francisco, CA, USA.

[2] Vladimirova, T., Bridges, C.P., and Prassinos G. *Characterizing Wireless Sensor Motes for Space Applications.* Proc. Of II NASA/ESA Conference on Adaptive Hardware and Systems, 5-8 August 2007, Edinburgh, Scotland, UK.

[3] A. Kalman. PicoSatellite *Programming within the Constraints of the 1kg, 10x10x10cm CubeSat Standard.* Second IEEE Conference on Space Mission Challenges for Information Technology, 16-20 July, Pasadena, California.