White Paper

Ad hoc sensor networks

www.thalesgroup.com

THALES

Author	Tim Baugé
Date	July 04
Reference	NET040702
Issue	Issue 1

Abstract

This white paper looks at the application of ad-hoc networking technology to sensor networks. It describes the principles behind ad-hoc networking and presents some of the solutions proposed for sensor networks. It particularly focuses on the need to adapt to networking strategy to the sensor's capabilities, design and application.

Key words

Ad hoc, sensors, network routing, sensor networks

Thales

Thales designs, develops and implements advanced electronic solutions, which meet the communications, information and security needs of people in countries throughout the world. Its activities cover three major markets: Information Technology and Services, Aerospace and Defence. The Thales group has operations in more than 30 countries and totals 65,000 employees world wide.

Thales Research and Technology (UK) Limited

Thales Research and Technology (UK) Limited (TRT (UK)) is the UK arm of the Thales corporate research centre. The activities within TRT (UK) are subdivided into 3 main areas; Navigation, Sensors & Signal Processing and Network Systems. In addition to providing support for Thales business objectives, TRT (UK) offers a wide range of consultancy and development services to European Government Agencies and to industry throughout the world.

Thales Research and Technology (UK) Limited
Worton Drive, Worton Grange
Reading, Berkshire, RG2 0SB, UK

e-mail: networks@thalesgroup.com

Ad-hoc networks

Principles

As far back as the early 1970s the American Department of Defence financed research into infrastructure-less packet switched wireless networks. It is only in recent years however - with the rise of personal computing and the miniaturisation of devices - that commercial interest has become wide spread.

The principle behind ad-hoc networks is to achieve self-organising networking between wireless devices without external infrastructure. Nodes should be able to come together and perform multi-hop communication using each other as routers without centralised or manual configuration. Typical example applications range from spontaneously networking delegate's laptops and PDAs in a conference room to integrating fire brigade, medical and rescue services' communications at a disaster scene.

Ad-hoc sensor networks

Sensor networks are often quoted as being candidates for ad-hoc networking technologies. The deployment of large numbers of sensors prevents manual configuration, and low power availability restricts the range of wireless communication technologies, requiring nodes to relay information back to data sinks via other nodes.

In this white paper, we examine which characteristics of sensor networks are particularly conducive to the use of ad-hoc networking technologies, and describe some of the solutions which have been proposed.

Sensor network taxonomy

The concept of “Sensor networks” is very broad, and covers a plethora of network types. What is considered to be a sensor is open to debate, and although “sensor networks” are often associated with MEMS based large scale networks, this is not necessarily the case.

We identify three categories of parameters which help to characterise a sensor network.

Node hardware parameters

This set of parameters captures the sensor platform capability. Relevant metrics include:

- Power resources. Some sensors can have near unlimited power resources if they are mains powered. Others will rely on a small battery for their entire lifetime.
- Node lifetime. This is tied in with the power availability, but also their deployment strategy. Some sensors are too expensive to be disposable and will be positioned in safe locations. Others are designed to have short life expectancy.
- Processing capability. This feature is again related to power availability, but also to cost related design decisions. The processing capability available for the networking functionality is likely to be related to the sensor processing requirements.
- Link capacity. Technologies such as the IEEE 802.11 and 802.15 families of standards illustrate the variety of capacity which can be achieved.
- Link range. From short range (few meters) to longer range (hundreds of meters) for typical commercial wireless PAN/LAN technologies.

Sensing data parameters

The sensing capabilities of the node are only relevant to the network from the perspective of the transmitted data. Sensing data parameters used to characterise the network include:

- Traffic matrix, i.e. who are the communication sources and sinks. Some networks have purely unidirectional communication patterns. Other models require sensors to process requests, for example.
- Traffic profile. Some sensors will transmit continuous data, while others operate with bursts of information. Many sensors are not continuously on, but sleep for large periods of time and only send periodic data, or even irregular alarm type information.

THALES

Network parameters

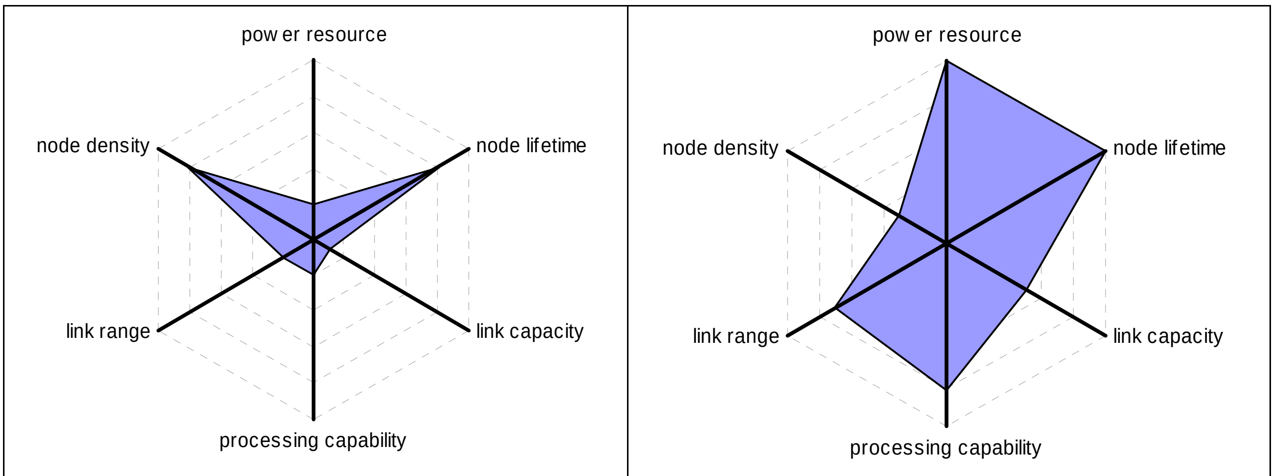
The network wide parameters complete the description of the sensor network. Parameters include:

- Node homogeneity. Some networks contain only one type of node. Other will have a variety of types, based on different sensing functions or communication functions (data aggregators for example).
- Node density. The number of nodes is an important parameter for the network, but also their geographical distribution. This needs to be related to the range of the communication technology in order to determine the impact on network topology.
- Connection to other networks. Some sensor networks are designed to operate in isolation, while others are required to connect to other networks. This places constraints on the design of the communications within the sensor network.

Many of these parameters are interdependent, leading to some common or unworkable combinations. They do however allow a description of the sensor network. The examples provided in Figure 1 show a visualisation of the quantitative parameters.
A disposable, low complexity sensor is typically limited in it's power resources, but requires a reasonably long lifetime. The combination of low power and low cost (disposable node) will require a low capacity link with short range, and limited processing capability. This will have to be offset by a high node density to provide network connectivity. At the other extreme, a high complexity vehicular based sensor for example will have near unlimited power and life expectancy. It may trade off link capacity for range in it's communication technology, and contain high processing capability. The high link range will allow for a low node density as far as communication is concerned.

Different solutions for different networks

The purpose of defining this sensor network taxonomy is to capture the requirements and constraints, and to adapt the networking solutions to the sensors. The two examples presented in Figure 1 are at different ends of the requirements spectrum. The high complexity sensor may be able to operate over a general purpose network, as the sensor has typical characteristics of standard handheld computing devices. The disposable sensor on the other hand presents a very different challenge, as the processing capability, power availability and link capacity preclude the use of protocols designed for main stream computing platforms. A much more integrated network design is required.
The following sections present some typical networking solutions.



Disposable low complexity sensor	High complexity vehicular based sensor

Figure 1: Sensor network characterisation

THALES

General purpose solutions

General purpose solutions based on the now ubiquitous Internet Protocol (IP) are being developed in particular in the Internet Research task force (IRTF) and Internet Engineering Task Force (IETF). These efforts assume an IP stack in each node, and mainly address the auto-configuration of nodes, routing and quality of service in the network, and inter-network integration. These solutions are attracting much attention and are rapidly gaining in maturity. The benefits of using standard technologies must however be weighed against the cost on node resources to run the protocols. Moreover, the layered approach favoured in these solutions produces network solutions that may not be optimised or even suited to the underlying wireless technology.

Tailored solutions

Sensors presenting constraints which preclude the use of general purpose technologies require tailored solutions. There are two levels of enhancement:

- Design of each layer to meet the sensor network requirements. For example, nodes may not need to be individually addressable, or may need MAC protocols adapted to very low duty cycles.
- Vertical integration of transmission, links and network technologies to increase efficiency with respect to power and processing.

The design of such a network requires cross discipline engineering, to provide efficient algorithms at all layers as well as efficient hardware and software implementations. The μAMPS project at MIT is one example where integration of advanced novel concepts and technologies at multiple layers is demonstrated [1]. The μAMPS microsensor focusses on power efficient and co-operating physical, link and network layer algorithms as well as power saving hardware techniques.

Networking examples

A number of novel networking concepts have been suggested for ad-hoc sensor networks. We will briefly describe a few here in order to illustrate the variety of approaches which can be used for specific applications.

Directed diffusion [2]

Directed diffusion is a data centric, query based, information dissemination mechanism. It is based on the flooding of sensing data requests, specifying geographical area of interest, duration of the interest, frequency of reporting etc. Nodes which cannot produce the requested data forward the request to nodes which might (based on their location for example) be able to respond. Nodes which can respond may still forward the request to other nodes which can assist (maybe the node cannot cover the entire geographical area of interest, or cannot resolve sensing uncertainties without neighbouring nodes' input). Nodes which can respond transmit the reports along the reverse path taken by the request. Aggregation, filtering or fusion may occur along the way based on state information stored by nodes during the request processing and forwarding phase. While the basic concept behind Directed diffusion is quite simple, the detail is very complex in order to produce a workable system which is scalable and efficient.

Rumour based protocols [3]

Rumour based routing is aimed at sensor networks which report events rather than continuous state. Two traditional approaches are either for sinks to send notification requests to all potential sources (i.e. a node interested in a particular event will register it's interest with all sensors), or to send event notifications to all nodes when something happens, which no longer requires active registration. Rumour based routing takes a hybrid approach, on the basis that if a well chosen subset of network nodes are notified of an event, interested parties will always have a node close to them which knows a route to the event. This avoids having to flood the network with either event notifications or requests. The "rumour" terminology comes from the fact that a node interested in an event will find out second hand where it occurred. This approach is clearly not suitable for time critical information such as alarm systems.
The two main problems to be solved in such an approach are the choice of a suitable subset of nodes for proactive event notification, and the method by which an interested party discovers such a notified node. This can be performed through random walks relying on statistics to ensure the proximity of any given node to the informed subset. In this case, random walks have also been shown

to provide a suitably efficient way for a node to find an informed node.

Negotiation based protocols [4]

Negotiation based protocols perform application layer flooding, based on data content as well as other parameters such as resource availability for example. Data dissemination is based on hop by hop flooding, meaning that each node in the network receives the data from its neighbours. To overcome the inefficiency of simple flooding algorithms, neighbours negotiate the data transfer using sensing metadata. Actual sensing data is only exchange if the destination node does not already have the data. Metadata aggregation can be performed so that many pieces of data are negotiate simultaneously. This approach is only appropriate for sensor networks where all nodes need notifying of all information and present inherent scalability issues.

Conclusions

In this white paper we have briefly presented a variety of networking approaches which can be applied to sensor networks, from IP based solutions to highly integrated and specific solutions. Ad-hoc techniques are particularly relevant to all these approaches as they remove the burden of strategic network driven deployment and configuration. The performance of the sensor network is critically dependent on the choice of networking strategy, which must be adapted to the sensor and it's application.

The Networks Group at Thales Research & Technology (UK) have extensive experience in the design and analysis of ad hoc networks, with capabilities in consultancy, simulation and testbed prototyping.

References

1 R. Min, M. Bhardwaj, C. Seong-Hwan, N. Ickes, E. Shih, A. Sinha, A. Wang, A. Chandrakasan, "Energy centric enabling technologies for wireless sensor networks", IEEE Wireless Communications, August 2002.

2 C. Intanagonwiwat, R. Govindan and D. Estrin, "Directed diffusion: A scalable and robust communication paradigm for sensor networks", Proceedings of the Sixth Annual International Conference on Mobile Computing and Networking (MobiCOM '00), August 2000, Boston, Massachussetts.

3 D. Braginsky, D. Estrin, "Rumor routing algorithm for sensor networks", Procedings of the the 2002 ACM International Workshop on Wireless Sensor Networks and Applications, September 28, 2002, Atlanta, Georgia, USA

4 J. Kulik , W. Heinzelman , H. Balakrishnan, "Negotiation-based protocols for disseminating information in wireless sensor networks", ACM Wireless Networks March 2002