Computer simulation of radio systems by agent based modelling

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Abstract

Agent Based Modelling (ABM) is the current hot topic in numerical simulation. ABM is based on the notion that a large number of individual nodes, having with behaviour determined by simple rules, can sometimes lead to the emergence of complex overall system behaviour. This idea can be applied to the protocols used in Wireless Sensor Networks (WSN) and promises a practical method of estimating the key performance parameter of battery life.

The use of simulation is particularly important for WSN validation, as it is clearly impractical to experimentally check a system with many nodes over its intended life of years in extreme interference scenarios. The current state of applicable simulation tools is reviewed and an example of actual simulated radio system performance presented.

Introduction

Wireless Sensor Networks (WSN) are ad-hoc networks formed by self-contained nodes having a sensor, for example a thermometer, and a radio transceiver. WSN may form part of ‘smartdust’ systems where the nodes are referred to as ‘motes’. Radio traffic is of low data rate and infrequent with the key performance parameter being battery life which may be up to ten years. Simplex operation has been used in the past and operates tolerably well. The sensor node transmits when an event occurs (timed or external) and a central (mains powered) point receives this signal. Battery life can be estimated from a simple understanding of the transmitter current, transmit time and standby current.

A radio transceiver at the sensor node can bring many advantages. Rather than transmitting for a long period in an attempt to ensure reliable reception, the node issues a short message, which is acknowledged by the central point. This is a slightly more complex protocol, which clearly results in the battery life becoming a function of the radio environment; if ten retries are required because of interference then ten times more charge is taken from the battery.

The radio message may fail to be received for various reasons: external interference, local nulls in signal level, and internal interference. ‘Internal’ means transmissions by other nodes within the system that block the channel. If a large number of nodes are placed together then it can be anticipated that the system will fail and battery life will be greatly reduced; there is a requirement to predict this failure point.

A mesh topology removes the idea of a central point and allows the nodes to route messages in many hops. This is an attractive idea as the range is naturally increased but in addition network reliability should be better as more that one path provides useful diversity. The battery life of each node then becomes a very complex function of radio environment and protocol used within the network.

We note that the currently emerging standards such as Bluetooth 4.0 low energy (BLE) are attempting to address this protocol requirement but appear to be restricted to 2.4GHz operation and don’t address the likely use of the 868MHz ISM band.

Battery technology

An example of battery technology is the CR123 primary lithium manganese dioxide non-rechargeable cell. It has a shelf life of ten years after which it has lost just 5% of capacity of 1.3Ahr. A radio taking 20mA for 2 seconds per hour would exhaust the cell in about ten years. The availability of adequate battery technology is illustrated by the fact that these cells retail for about £2.

The need for simulation

Methods of predicting battery life in WSN seem to be limited to simulation. An analytic method, which includes the complexities of protocol together with variations in radio environment, seems hard to imagine. The experimental method would require a system having many nodes running for a long period of time in a variety of radio environments; this is also hard to envisage.

Simulation tools available

A table comparing simulation tools for Wireless Sensor Networks was published on the Internet by Markus Becker of University of Bremen [Becker]. This table is a very useful reference as it includes an assessment of ability to predict energy use. Only the TOSSIM discrete event simulator [TOSSIM] is marked as having this facility and it appears to be unsupported now. TOSSIM is only applicable to the TinyOS operating system [TinyOS] in any case.

Many of these tools are developed by universities as part of their research and are not suitable for direct use by engineers attempting to evaluate a particular protocol. Normally it is necessary to re-compile the whole simulator to configure it for a specific simulation. The most well known example is NS2 from The University of Southern California, Viterbi School of Engineering's Information Sciences Institute [NS2].

Note that simulation of the code which implements the protocol running in a sensor node would be by running that same code in a PC. Although the test harness around the protocol code would be a simulation of the real world, the protocol code would be “actual” rather than simulated.

Agent Based Modelling (ABM)

A good explanation of ABM is provided by The University of Rome who used NS2 to predict the behaviour of the Internet in the event of a natural disaster [University of Rome]. They provide the following text:

“…the whole model of a target system is obtained considering a population of interacting agents. The key characteristic of an agent is that it exists as an individual entity with location, capabilities, and memory. From the interaction among these agents “emerge” behaviors that are not predictable by the knowledge of a single agent.”

The behaviour of a WSN having many individual nodes can be see as an appropriate use of ABM.

ABM maps directly to the C++ concept of classes and objects. A C++ class can form a generic description of a node, which can then be used to create numerous instance objects, which represents the individual nodes within the simulation program.

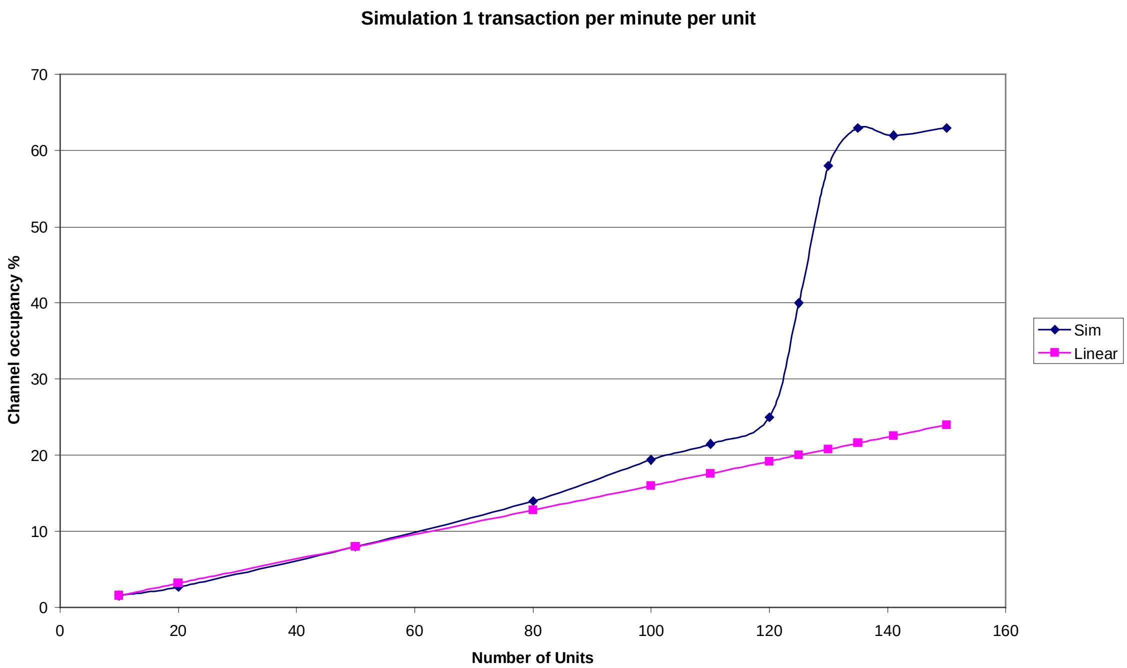
Practical experience

The GTR5i radio terminals manufactured by MK Consultants (UK) Ltd [MK] were utilised to form a network where a large number of sensors transmitted a message, which was acknowledged by a return message from the central point. If this failed then a number of re-tries were made. Although fairly simple in concept this arrangement led to two questions which were difficult to answer without resorting to simulation.

- How many sensors can be deployed before the channel becomes overloaded ?
- Is the ‘back-off’ algorithm is adequate ?

Back-off refers to a pseudo- random delay inserted between the channel becoming available and a message being sent, to avoid multiple nodes transmitting at the same moment.

A console application was written in Microsoft C++ using the ABM principle and the system simulated for long periods of (simulated) time. The number of nodes was varied in order to establish the point at which failure through over loading occurred. The simple case of no interference apart from 'internal' interference was studied.



For this particular set of parameters it can be seen that the linear scaling of channel occupancy with number of nodes breaks down at about 120 nodes and about 25% occupancy of the channel.

Similar simulations without the back-off algorithm in place did very occasionally result in a lock-up condition. Note that this lock-up condition, which occurs when two sensors initiate transmission at the same moment, is a rare event and it is necessary to simulate a large amount of data to be increasing certain that there is no concealed fault.

This radio system modelled here has been in successful operation for over two years.

Conclusions

Wireless Sensor Networks have the promise of operating for ten years without maintenance. To be sure this lifetime is really achieved some attention has to be given to the effect of radio environments and protocols on battery life. Simulation tools to do this work remain in the domain of experts within universities. A more straightforward method seems desirable.

Acknowledgements

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References

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