Multiple Radio Simulation Support for Cyber Physical Systems

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Overview

Cyber-Physical Systems (CPS) are emerging as a new computing paradigm that combines distributed sensing and actuation. These systems are expected to be deployed in large scale of hundreds to thousands of nodes, which introduces challenges regarding scalability of communication. CPS with high spatial density can lead to low link qualities, high congestion, and ultimately, low packet rate. Researchers have been using network simulators to explore solutions to these challenges in large scale systems.

Recent deployments include multiple radios within a CPS node and demonstrate potential in resolving scalability problems. However, current simulators do not support multiple radios. This paper presents the design and performance evaluation of our multiple-radio extension of TOSSIM, a wireless sensor network simulator. Our initial results show that, as expected, multiple radio nodes provide a better packet rate than single radio nodes, and that our simulator scales well with an increasing number of radios per node.

1 Radio diversity

Multiple-radio CPS networks have already been deployed [1], and show improvements [4] in comparison to single-radio networks. If too many nodes try to communicate at the same time on the same frequency, their packets interfere, which reduces end-to-end packet rate. Multiple-radio nodes can increase the available bandwidth. By sending on different channels simultaneously, nodes can improve their packet rate or separate control and data transmission more effectively.

Another benefit of multiple radio nodes is the improved coverage provided by frequency diversity. By choosing radios that operate at different frequency bands, we increase the likelihood of communication coverage for the deployment region of interest. Furthermore, we can expect a gain in robustness within time-varying lossy or multi-path environment. Whenever the link quality on one radio degrades, the node can switch to the other radio for communication, unless the link degradation of the two bands is correlated.

The expected benefits of multiple radio nodes still require verification. Empirical testing of these systems is both expensive and time-consuming, especially as they grow in size. An alternative approach is to conduct computer simulations to evaluate the performance of multiple radio CPS. The remainder of this paper focuses on our implementation and validation of multiple radio support in the TinyOS [2] simulator.

2 Multiple radio support in TOSSIM

TOSSIM [3] is a discrete event-based simulator for TinyOS networks. Using the same files, an application can either be compiled and installed on a mote, or compiled into the TOSSIM framework and run on a PC. This lets users test and debug their algorithms directly on their computer. Our extension to TOSSIM preserves this feature.

Figure 1: TOSSIM Implementation

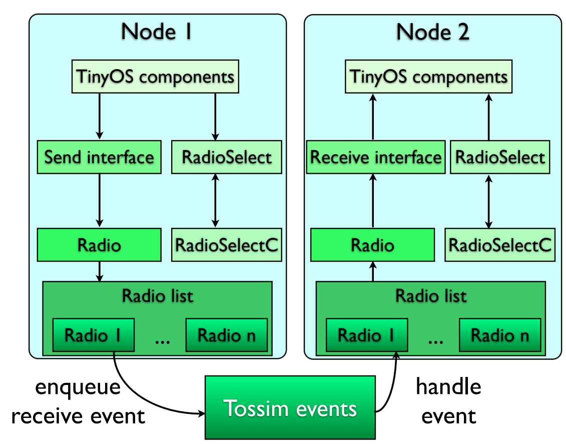


Figure 1 shows our design for multiple radio support in TOSSIM. Motivated by the original implementation of TOSSIM, we have chosen to keep the same interfaces with single radio configuration files. This ensures backward compatibility for our extension.

Our main addition to TOSSIM is the RadioSelectC component, which provides an interface to write and read a radio ID in the packet's header. This radio ID is used by TOSSIM at the sender to select on which radio to send. Each radio can use a different model, reflecting different options for radio frequency, modulation, or data rate, as configured during initialisation. This framework supports any number of radios.

3 Results

To test the simulator, a simple application has been developed. A set of nodes periodically send data to a base station, using one of their radios, randomly selected for each packet. Once the base station has received 1000 packets, the experiment stops. We run the experiment several times, varying the number of radios or the number of nodes.

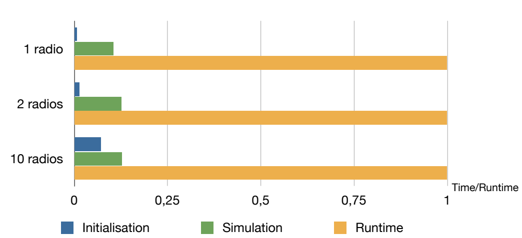
Our evaluation metrics are:

1. Initialisation time: Time it takes for TOSSIM to set up the network
2. Simulation time: Time it takes to run the simulation
3. Runtime: Time it would take in reality to run this experiment (assuming the network is already deployed)

All of the experiments are run on a virtual machine implementing a single 2.50 GHz Intel Processor, with 256Mb of RAM.

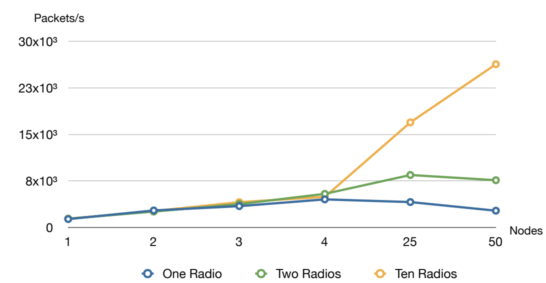
First, we use a set of 5 nodes, each node sending a data packet every 250ms, and we vary the number of radios used per node. As we can see in Figure 2, even if the nodes implement 10 radios, the simulation runs faster than the real time. The time it takes for TOSSIM to conceive such a network is in milliseconds, whilst on the field it would have taken hours to set up the nodes and deploy the network.

Figure 2: Simulator evaluation



In order to test the advantages of using multiple-radio nodes, we use the same experiment, but vary the number of nodes. In addition, we set the sending period to 2ms, so that we can see the impact of interference on the results. Figure 3 shows the aggregate packet delivery rate at the Base Station. Note that TOSSIM does not emulate CPU computation time, thus the aggregate rate would be much smaller on the field. With an increasing number of nodes, the rate initially increases, but then decreases due to radio packet collisions. Using more radios reduces those collisions, thus improving the packet delivery rate and reducing the simulation time and the runtime.

Figure 3: Multiple radios testing



4 Future work

Although some examples of radio-diverse sensor networks have been run in the simulator, we intend to validate it with some tests. Those tests will consist of deploying CSIRO's new Opal nodes with multiple radios and compare the results obtained in the field with the results of our simulations.

We also intend to use the simulator to work on other opportunities provided by radio diversity. These include improved localisation algorithms and enhanced routing protocols on the basis of multiple radios.

References

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