Mean-field performance analysis of a hazard detection Wireless Sensor Network

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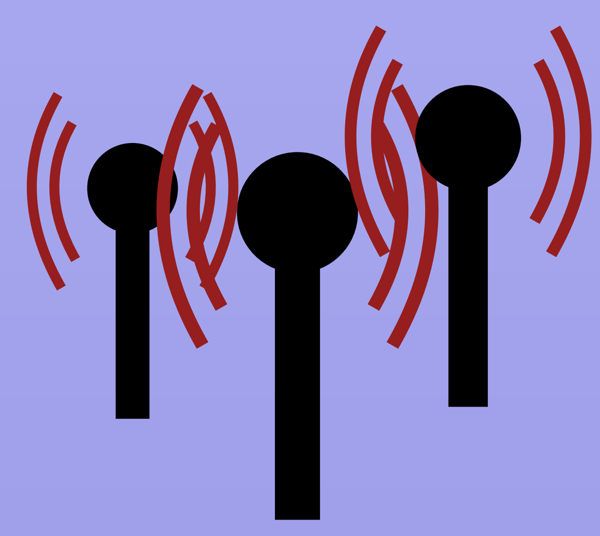
The challenge

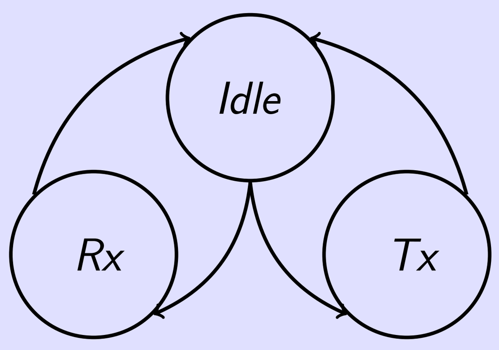
Efficient design and installation of WSNs is still a complicated task. This is due to the hardware limitations of sensor nodes and the unreliable nature of the wireless medium, which makes it hard to guarantee QoS agreements. As a consequence, many protocols have been proposed for different scenarios. However, since sensor node applications are mostly custom stacks of different protocols, engineers need to optimise them for individual networks to obtain the desired performance. Traditionally this is done using low-level simulations and test beds. The latter is expensive and time consuming, whereas low-level simulations generally do not scale for large systems [1]. To mitigate this problem we present mean-field analysable PCTMCs [2] as an alternative way to model and analyse WSNs efficiently and potentially provide a tool for faster protocol parameter optimisation.



Spatial Population CTMC

How? Spatial Population Models that can be represent as large *Continuous Time Markov-Chains*

- Discrete state agents
- Agents replicated in space
- Location dependent interactions
- Measure moments of agent state population distributions over time



Mean-field analysis

Populations moments, e.g. $\mathbb{E}[\#\mathit{Idle}]$ can be efficiently approximated using systems of ODEs. Unlike simulations, larger population do not increase the solution time. However, there are certain challenges

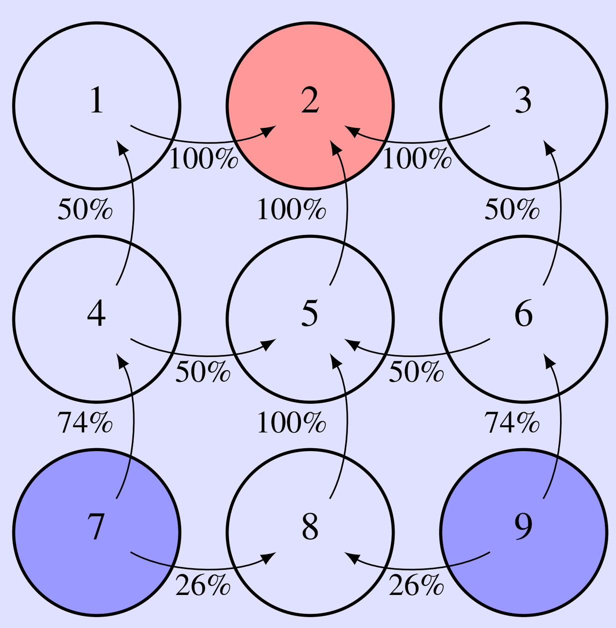
- Mean-field analysis is most accurate when populations are large
- For large spatial systems it is only feasible to approximate mean and variance of populations
- We generally assume exponentially distributed delays

Case–study: Analysing effects of topology changes in hazard detection WSNs

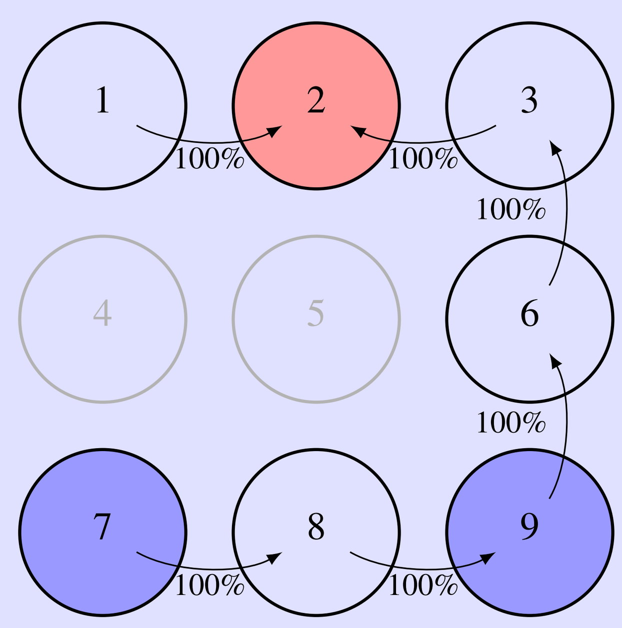
Suppose we were to design a fail-safe emergency monitoring WSN using a routing mechanism as described in [3, 4]. Before installing the system we need to know about the following transient and steady-steady state behaviour of the network during and after reconfigurations:

- Buffer occupancy
- Throughput
- Latency

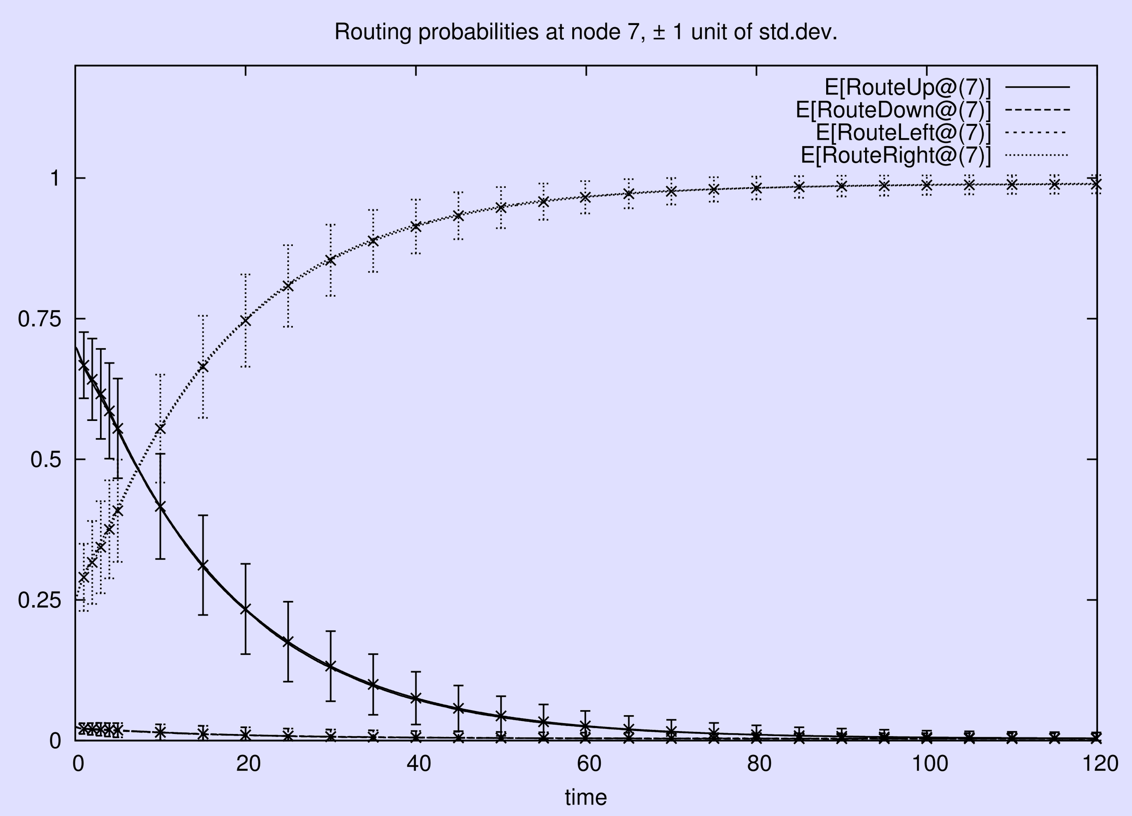
The diagrams on the left show the steady-state routing preferences of individual nodes in the network, before (cf. Figure 1a) and after (cf. Figure 1b) the breakdown of nodes 4 and 5. The graphs below highlight the transient effects of the resulting topology change.



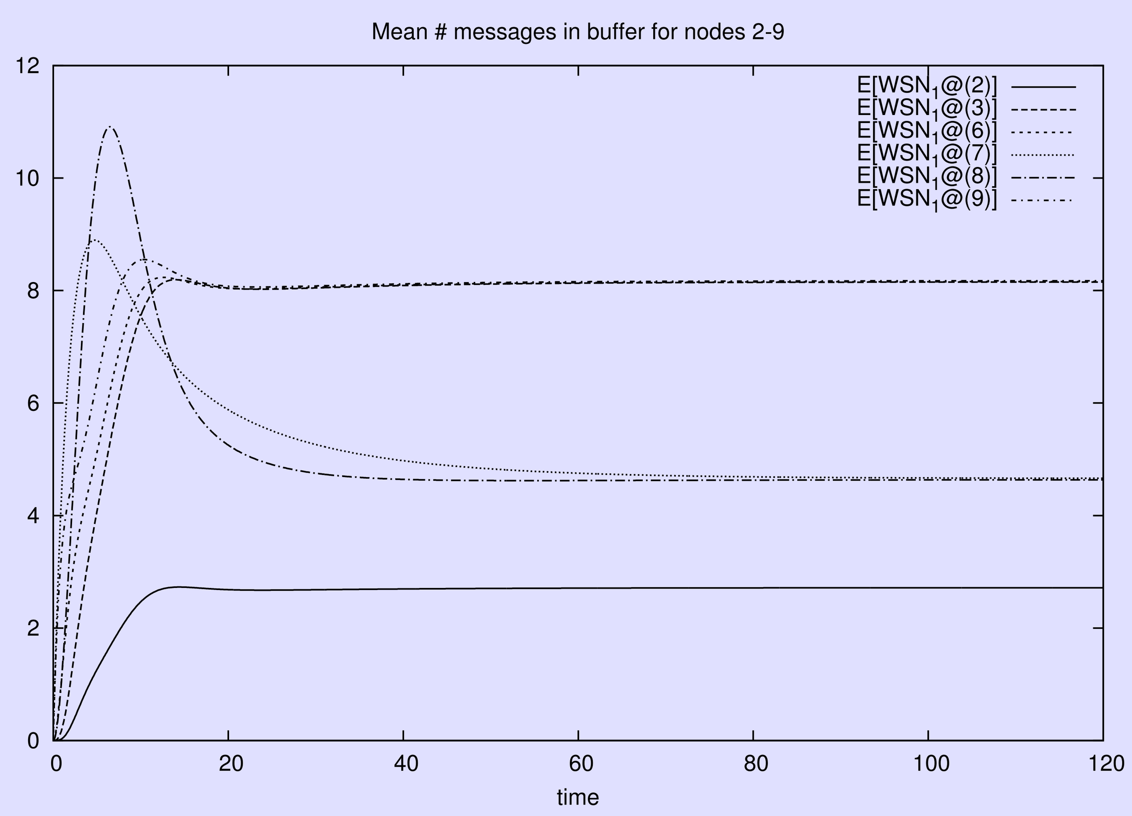
(a) Routing in fully operational network



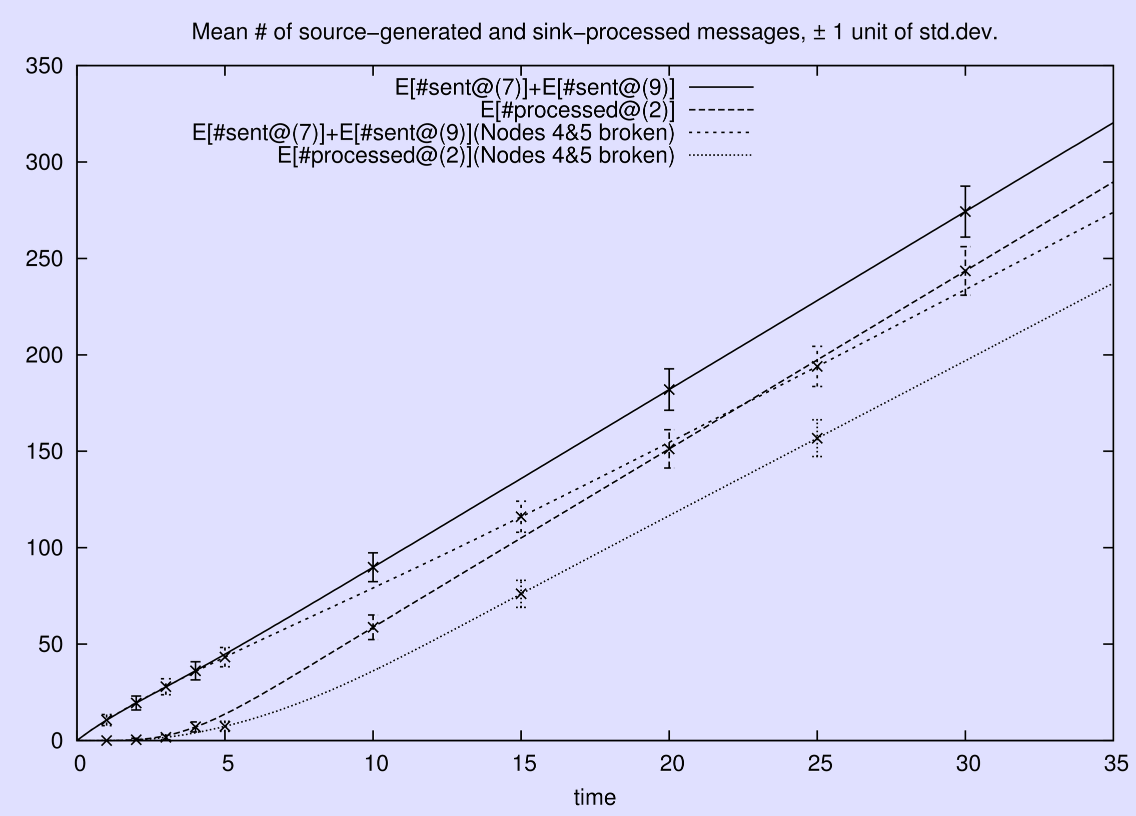
(b) Routing after breakdowns



(c) Routing probabilities at node 7. As node 4 breaks, the node starts routing more messages through node 8.



(d) Avg number of messages in buffers. We see a temporary surge in buffer levels as nodes adapt to the new topology.



(e) As expected, avg throughput decreases and latency increases as nodes break.

Conclusions and future work

Conclusions:

- Mean-field analysable PCTMC models can capture dynamics of fail-safe WSNs
- When optimising protocol parameters this could be used to reduce the amount of low-level simulation needed

Further work:

- Show that PCTMC models of large, complex WSNs can also be analysed efficiently using mean-field methods
- Validate PCTMC model predictions against low-level simulation results
- Investigate use of PGSMP models with deterministic delays to represent realistic duty-cycle behaviour [5]

References:

[1] E. Egea-Lopez, J. Vales-Alonso, A. Martinez-Sala, P. Pavon-Mario, and J. Garcia-Haro, "Simulation Scalability Issues in Wireless Sensor Networks," *IEEE Communications Magazine*, vol. 44, no. 7, pp. 64–73, 2006.

[2] R. A. Hayden and J. T. Bradley, "A fluid analysis framework for a Markovian process algebra," *Theoretical Computer Science*, vol. 411, no. 22-24, pp. 2260–2297, 2010.

[3] D. Bruneo, M. Scarpa, A. Bobbio, D. Cerotti, and M. Gribaudo, "Markovian agent modeling swarm intelligence algorithms in wireless sensor networks," *Performance Evaluation*, vol. In Press,, 2011.

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[5] R. Hayden, "Mean field for performance models with deterministically-timed transitions," in *9th International Conference on Quantitative Evaluation of Systems (QEST 2012)*, (London), 2012.