Modelling and Analysis of k-Bounded Queuing Systems in Wireless Sensor Networks

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Summary

In Wireless Sensor Networks (WSNs), scheduling and resource provisioning strategies have been heavily scrutinized. It is therefore an open problem to model and compare existing resource scheduling algorithms and design formal approaches for safety analyses (invariant analysis, state space analysis, co-reachability etc). This research study introduces Petri Net analysis as a feasible approach to check for significant features like fairness, deadlock avoidance and steady state reachability in a WSN. The agenda of this research study is to introduce and demonstrate how Petri Net Formalisms and its variants can be employed to the above mentioned use cases.

Scope of the research

In WSNs, sensors are deployed to capture physical parameters such as temperature, humidity, pressure etc. of an environment. The corresponding data is aggregated at the Base Station (BS) to conduct statistical measurements. However it is observed that in certain use cases, a recursive dependency exists which could potentially lead to deadlock scenarios. In such scenarios, even a fail-proof rollback mechanism is insufficient to recover to a steady state, thus terminating the entire WSN. It is therefore extremely significant to conduct sufficient testbed analyses, in particular state space analyses and argue if existing systems can eventually reach an absorbing state. The central focus of this study is to demonstrate formal methods to perform such analyses.

Modelling of Queuing Systems

WSNs constitute of severely constrained sensing equipments embedded with microcontrollers that further constitute a wireless communication network. Due to its limited hardware and computing capacity, WSNs share key responsibilities such storing data by means of queues. Hence, the primary aim of this research study is to employ formal mathematical concepts namely Markov chains & Queuing theory to derive formal proofs of the suitability of different types of queues such as $M|M|1$, $M|M|\infty$ and $M|G|1$ queues in WSNs. In this study, students would employ the simulation platform OMNet++ to model simple $M|M|1$, $M|M|\infty$ and $M|G|1$ queues and simulate their operational semantics in context with WSNs. Students will compare and contrast different scenarios where shared resources are expected to form a dependency graph, hence prone to deadlock situations. Students will attempt to solve this problem by detecting algebraic loops in the queuing system using Petri Nets and potentially argue whether such queuing systems can be stabilized eventually.

Petri Net Analysis

Another interesting challenge in WSNs is to design fair algorithms for workload and resource distribution.Typically in WSNs, an apriori schedule or priority list is maintained which overloads the existing MAC-layer protocol and as a consequence, many sensor nodes starve to transmit data. To address this problem, students will use Platform Independent Petri Net Editor (PIPE) 5 as a formalism to model different queuing systems. Essentially, students will argue and provide remarks on the fairness of resource allocation and reachability of absorbing state based on conclusions derived from the generated models. Additionally, students will also attempt to use Low-level Petri Net Analyzer (LoLA) as a primary tool to formally check the Petri Net models by introducing for implicit corner cases.

Student Outcomes

The major emphasis of this research study is to train students to adapt with the requirements and work environment of a directed research study. Essentially, it will provide a notion about the differences between independent and directed research. Students will learn a new formalism namely Petri Net, understand its operational semantics and build models to abstract different problem scenarios, specifically for WSNs. Students will be also introduced to conducting numerical analyses of Petri Nets to further solidify their foundation on such formalisms and later on, will employ Petri Nets to solve a research problem. Students will gain hands-on experience with industrial tools like OMNet++, PIPE and LoLA to perform Petri Net analysis for safety and state space analyses. Last but not the least, students will engage in a high-risk high-reward research setting and will develop key academic skills such as academic writing, scientific communication, thesis defence and peer presentation.

Expectations

Students are expected to indulge voluntarily in a directed research project contemplating on the given problem at hand. They are expected to produce convincing models and must transform their work into a scientific paper. The paper must conform with IEEE conference standards. Additionally, Students are expected to refrain themselves from asserting intellectual contributions as the nature of this research project is directional.

Prerequisite Coursework

**15MA207-Probability & Queuing Theory (or similar), **15SE201J- Object Oriented Programming Using C++, 15CS332E- Wireless Sensor Networks (not mandatory), 15IT444E- Network Simulation And Modelling (not mandatory)