ABSTRACT

The current era of the Internet of Things (IoT) has led us to a world of automation in almost every sphere of life, such as healthcare, home security, precision agriculture, etc. Wireless Sensor Networks (WSNs) serve as an important implementation tool to actualize the IoT in the real world. WSNs comprise a large number of inexpensive sensor nodes, each capable of sensing, processing, and transmitting environmental information to the sink node. These sensor nodes are vulnerable to failure due to external causes such as variability in environmental conditions, including rainfall, humidity, foliage, and internal reasons like noise, lack of battery power, hardware failure, random duty-cycle, etc. These internal causes enable a sensor node to exist in multistate such as ACTIVE, RELAY, SLEEP, IDLE, and FAIL in its entire lifecycle. To gauge the performance of such networks, reliability analysis of these networks becomes extremely important.

A WSN is an event-driven network that depends on the collective data provided by the sensor nodes monitoring a particular phenomenon. In such cases, the network is considered successfully operating if and only if a certain minimum aggregate amount of information is delivered to a given sink node. Thus, WSN reliability is defined to be the probability that the network can successfully transmit the application-specific required amount of flow to the sink node under such multistate nature of each sensor node. Further, owing to such multistate nature of sensor nodes, it is also important to quantify the capability of a WSN to provide adequate coverage of the region of interest. To quantify the flow-oriented reliability and coverage-oriented reliability of WSNs with multistate nodes, this thesis proposes new metrics: WSN Reliability ($WSNRel$), Area-Coverage Reliability (ACR) and Coverage-oriented Reliability ($CORE$). $WSNRel$ provides a minimal-path based approach to evaluate flow-oriented reliability of WSNs with multistate nodes. The proposed approach includes enumeration of shortest minimal paths from application-specific flow satisfying sensor nodes (source nodes) to the sink node. It then proposes a modified sum-of-disjoint products approach to evaluate WSN reliability in the presence of multistate nodes from the enumerated shortest minimal paths. Computing $WSNRel$ has been shown to be NP-Hard.

The metrics, ACR, and $CORE$, aim at quantifying the coverage-oriented capability of a WSN. To quantify ACR and $CORE$, Monte Carlo simulation approaches that utilize an energy matrix to check the capability of a WSN in satisfying the application-specific coverage-oriented requirement are presented. The energy matrix reflects the residual energy of sensors, the energy required to transmit data to the neighboring nodes, connectivity, and the sensors' multistate nature. A Discrete-Time Markov Chain model is presented to study the multistate behavior of sensor nodes while evaluating $CORE$. ACR and $CORE$ bring together WSN reliability, area coverage, energy efficiency, mobility of data collector or sink, random duty-cycle of nodes, and multistate nature of sensor nodes under a common umbrella. It is noteworthy to mention here that ACR considers sensors with 4 states and $CORE$ considers nodes with 10 states.

Lastly, to preserve the limited energy resources of sensor nodes, and maximize $CORE$, a multi-path split-flow routing scheme is presented. Depending on the sensor nodes' distance and residual energies, few rules that govern the splitting of flow through the multi-paths are formulated.

Simulations on benchmark networks as well as random networks are performed for each work showing the effectiveness of all algorithms proposed in this thesis. The proposed metrics will help the network designers to consider the metrics as a part of sensor network design and determine reliability quickly. The proposed metrics are advantageous in the sense that they pave the way towards a more realistic aspect of wireless sensor network reliability.

Keywords— Coverage area reliability, Markov chain, multistate nodes, network reliability, node energy, random duty-cycle, shortest minimal paths, sum-of-disjoint products, wireless sensor network.