

consistent with the intuition in [5] that a higher energy will increase node lifetime. Increase energy has lead to node acting cooperatively for longer period.

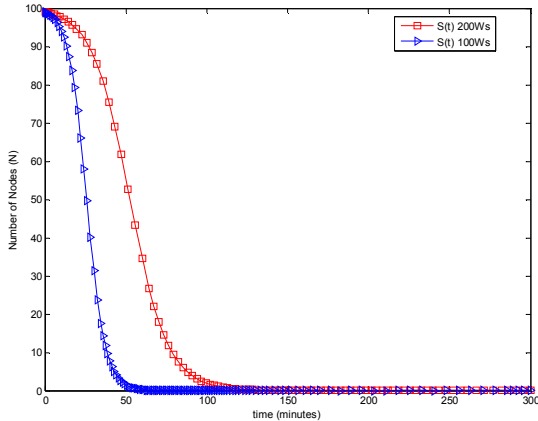


Fig. 11 The effect energy towards Susceptible Event

However, the increase of energy actually prolonged the lifetime of malicious node and slightly reduces the correlated degree because of an increase in infection rate. This can be seen in Fig. 12, node with higher energy will remain in malicious state and continue spreading correlated event. This is dangerous situation as the node may impact network survivability severely.

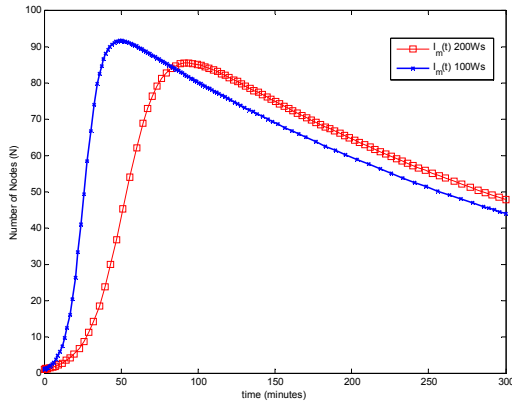


Fig. 12 The effect of energy to Infective Event (Malicious Node)

D. Model Validation

An extensive simulation of epidemic spread to validate the correlated node behavior model and check with analytic results have been performed. Data from simulation is compared with Weibull distribution for analytical data. Weibull distribution is widely use in reliability engineering to model lifetime distribution. $F_A(t)$ is considered as selfish cumulative distribution function (cdf) and $F_C(t)$ is malicious distribution function (cdf). The Weibull function used in this paper is known as the two-parameter Weibull distribution, define as

$$W(\alpha, \beta) = 1 - \exp(-(t/\beta)^\alpha) \quad (12)$$

where α and β are usually called the slope (or shape) parameter and scale parameter, respectively. From simulation result, average transition from cooperative to selfish and from cooperative to malicious are $\approx 45s$ and $\approx 51s$, respectively. If let $\alpha_A = 0.5$ and $\alpha_c = 0.6$, then $\beta_A \approx 9$ and $\beta_C \approx 19$. From Fig. 13 and 14 clearly shows that Weibull function in equation (12) match with simulation results. The $S(t)$ plots show clearly how likely a node is surviving after a certain time. Further, the distribution can also be used to estimate the number of cooperative nodes. For example in Fig. 14, the probability that a node still in cooperative state within 50 minutes is 0.1, which also implies that 90% of nodes will become selfish within 50 minutes if they are compromised. On the other hand, at about 50 minutes, 100% of nodes become malicious node and the entire network is compromised. From the analysis, the spreading of correlated node behavior in malicious state is faster once more nodes are in infected state. Therefore, these accumulated malicious attacks may impact network connectivity severely and isolate more and more nodes. In the case of selfish node, the spreading time is less than malicious node; however, selfish node is capable to create severe network portioning due to node failure from energy depletion.

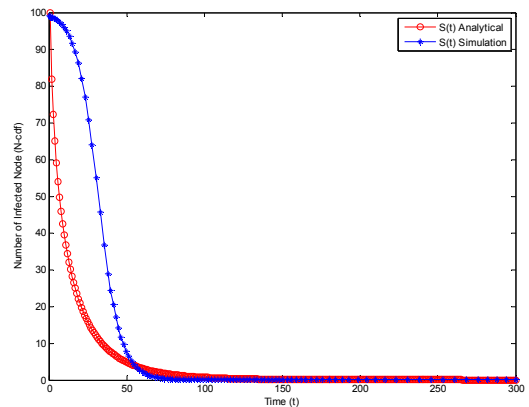


Fig. 13: Probability of nodes become selfish nodes

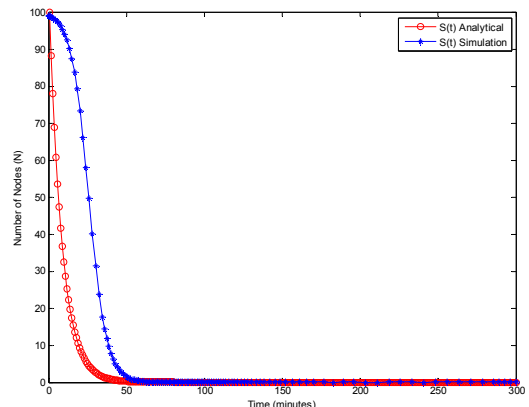


Fig. 14: Probability of nodes become malicious nodes

VI. CONCLUSION

In this paper, stochastic correlated node behavior model is studied which enable the efficient simulation of realistic scenarios of correlated node behavior for dynamic network topology in ad hoc networks. Then correlated degree is developed based on disease spreading in SIR model to capture the spread of correlated behavior. According to this model, a necessary condition for correlated behavior to spread in ad hoc networks is theoretically derived. Numerical analysis results are provided to demonstrate the validity of the model. As future work, more other factors will be considered to measure the impact of the correlated behavior in these networks, such as security limitation.

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