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ORIGINAL ARTICLE

Weighted delay prediction in mobile ad hoc network using fuzzy time series

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Abstract Several parameters like routing protocol, mobility pattern, average speed of mobile nodes, path length from source to destination, previous delay, etc., affect the end-to-end packet delay in mobile ad hoc network. But the nature of relationship between end-to-end delay and those parameters is still unclear. In this article, we have tried to establish a relationship among end-to-end delay, path length and previous delay. A regression equation is established between path length and end-to-end delay. The end-to-end delay is also represented as a fuzzy time series. The current end-to-end delay is then obtained by combining delay predicted by path length regression equation and fuzzy time series. The suitable weights of these two predicted delays are also experimentally determined. To the best of our knowledge, comprehensive analysis for packet delay estimation using various network parameters along with fuzzy time series has not been explored earlier. Based on various performance evaluation criterion, we found that by combining the predicted values of delay using path length regression and fuzzy time series gives satisfactory packet delay prediction in ad hoc network.

1. Introduction

The nodes in Mobile Ad Hoc Network (MANET) are mobile and continuously changing locations. They do not have any fixed infrastructure like base station, etc. They can relay packets to another node without using any base stations. Each node in MANET has a transmission range within which the signals received from that node are strong enough to extract meaningful information by other nodes. If two nodes happen to be within the transmission range of each other, they can communicate directly otherwise they use a number of links involving one or more intermediate nodes to communicate with each other. This mode of communication is called multi-hop

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communication. This is why MANET is called as multi-hop wireless network also. A path is the ordered list of links between a source and destination pair. The total number of links between a source-destination pair defines the path length between that pair. MANETs are often configured with smaller transmission ranges to avoid interference. Hence, path length happens to be greater than one for most of the time.

MANETs are highly appealing for a lot of applications like deep space communication, disaster relief, battlefield communication, outdoor mining, etc., due to their flexibility and distributed nature. To provide Quality of Service (QoS) for these applications, understanding the fundamental delay performance of such networks is of great importance [1]. The end-to-end delay is the time taken by a packet to reach its destination after it is generated at its source. Because of multi-hop nature and continuous movement of nodes, end-to-end delay in MANET is higher compared to other infra-structured network. However, the end-to-end delay modeling in MANETs is still a challenge for network research community. One of the primary reasons is very dynamic behavior of MANETs, like node mobility, interference, wireless channel/traffic contention, packet distributing, packet queueing process in a node and the complicated packet delivering process among mobile nodes. Still there does not exist any theoretical framework to efficiently depict the complicated network state transitions under these network dynamics. By now, the available works on end-to-end delay analysis in MANETs mainly focus on deriving upper bounds or approximations for such delay.

Narasimhan and Kunniyur [2] identified three main sources of delay in MANET. They are (i) multi-hop nature of network, (ii) channel access delay, and (iii) queuing delays at intermediate nodes. To reach the intended destination, each packet in MANET may traverse multiple hops where the packet is enqueued by a node for further processing and forwarded to other node if the node is not the intended destination. With each hop the delay keeps on increasing as the transmission and processing delay increases. But the exact nature of relationship between path length and delay is not known so far. For contention based Medium Access Protocol (MAC), the waiting time of the node increases exponentially for each collision. The channel access delay enhances the total delay even for low path length. The load on each node, the node density or the number of nodes in the network and the transmission power affects the channel access delays. At each node, the received messages are kept on a queue for further processing by the node. The length of the queue is a function of the load on the network and the routing protocols used. Queuing delay is a function of queue length. Although Narasimhan and Kunniyur [2] pointed out the main sources of delay in MANET but they did not quantified the effect of individual parameters on end-to-end delay.

Along with the causes suggested by Narasimhan and Kunniyur, node mobility pattern [3] also has a major role in overall packet delay in MANET. The node movement patterns in MANET vary depending on the applications and locations of network deployment. Like the movement of the soldiers will be influenced by the commander hence the nodes will also follow same pattern in a battlefield MANET. The movement of vehicles is restricted by obstacles or maps in a city-wide MANET. Widely varying mobility characteristics surely have an impact on the end-to-end delay.

In this article, we have tried to predict the future values of delay between a source destination pair based on the previous delays and current path length. We have proposed a weighted delay prediction mechanism using regression on path length and fuzzy time series on previous delays. We have used trapezoidal fuzzy numbers in the fuzzy time series. The reason using trapezoidal fuzzy number is that Liu [4] proved through extensive experiments that trapezoidal numbers give better prediction results than triangular fuzzy numbers used for the same purpose. To compare the performances of prediction models, we define several performance evaluation criteria (PEC) such as Root Mean Squared Errors *RMSEs*, correlation coefficient *R*, and Efficiency *E*. The results of models are compared with actual data and the best-fit model structure is determined according to criteria. In our opinion, this work will help the research community to analyze and model the delay parameter for MANET in a more comprehensive way.

The rest of the paper is organized as follows. A brief survey of works done related to network delay is given in Section 2. Fuzzy times series is explained in Section 3. We describe simulation environment in Section 4. The model development based on path length and fuzzy time series model is given in Section 5. The discussions on the results obtained are discussed in Section 6. We summarize our work and conclude in Section 7.

2. Related works

Gupta and Kumar proved in [5] that the optimal network throughput is obtained at the lowest transmission power that allows connectivity. The interference between simultaneous transmissions will be very low with smaller transmission ranges helping more nodes to communicate simultaneously. This however, increases the delay as the number of hops required to reach the destination increases. Sharma and Mazumdar [6] and Gamal et al. [7] ascertained the trade-off between the delay experienced and the throughput possible in the network. However, the channel access mechanism and the effect of collisions on delay were not considered in both the analyses. The relationship between the MAC delay and the neighbor number in mobile ad hoc networks, and an estimation method of the MAC delay is analyzed by Sheu and Chen in [8]. Sun and Hughes used two dimension finite-state Markov models to analyze the queuing delay [9]. They proposed that the end-to-end delay of a path can be estimated by adding all the node delays and link delays in the path.

Guo at el. [10] presented a scheme for predicting mean per-packet one-hop delays using neural network. They modeled the mean delays as a time series using (i) tapped-delay-line Multi-Layer Perceptron (MLP) network and (ii) tapped-delay-line Radial Basis Function Network (RBFN). The inputs used by them are (i) the mean delay time series itself only, (ii) the mean delay time series together with the corresponding traffic loads. They ignored the effect of any other parameter on delay as well as their scheme predict only one hop delay not the complete end-to-end packet delay. Hongyan et al. [11] used autoregressive models and neural network to predict Internet time delay. Tabib and Jalali [12] used feed-forward multilayer perceptron to predict Internet time delays. Both Hongyan et al. and Tabib et al. considered only internet time delay. They have not considered any other network types and their characteristics.