Fine-Grained Metrics for Quantifying Admission Control Performance in Mobile Ad Hoc Networks

Jianli Guo[1,2], Wei Wu[1,2], Xiaoxia Liu[3], Lianhe Luo[1,2],
Changjiang Yan[1,2], and Yuebin Bai[3]

[1] Science and Technology on Information Transmission and Dissemination in Communication Networks Laboratory, Shijiazhuang, Hebei, 050081, China
[2] The 54th Research Institute of CETC, Shijiazhuang, Hebei, 050081, China
[3] School of Computer Science and Engineering, Beihang University, Beijing 100191, China

Abstract. The admission control (AC) is one of the crucial components of in QoS-providing mobile ad hoc networks (MANET). The responsibility of AC is to estimate the state of the network resources and decide whether application data can be admitted without promising more resources. AC should achieve a right balance between admission accuracy and network resource waste. It aims to admit as many sessions as possible, while utilizing the network's resources fully and efficiently. Conversely, any inaccuracy in the admission decisions can result in the pledging of more resources than are available, leading to false admissions. However, the existing metrics are only network resource or performance related, thus, it is preferred to have a metric that can measure the effective AC protocols as it influences in achieving QoS demands of the sessions. Therefore, in this work we present observation-based admission control performance metrics quantifying the satisfaction of both single session and the entire network. Also we predict the possibilities of false admission and successful completion of a session and give discuss about the metrics. Finally, we proposed a design of feedback-based admission control using the metrics we presented for feedback parameters, the verification and implementation of our design and the effectiveness of the metrics is mentioned in the future works.

Keywords: admission control, evaluating metrics, mobile ad hoc networks, MANET, predict probability of false admission.

1 Introduction

As the progress in mobile ad hoc networks (MANETs), the desire to run real-time applications over MANETs increases. Real-time applications have strict requirements on the quality of service (QoS) provided by the network. These requirements have delivery rates of data packet, end-to-end delay, bandwidth or throughput-related constraints, etc. It is important that network resource should be adequate for the applications, otherwise the application will be inconvenient to use and user will suffer from bad experience.

P. Ren et al. (Eds.): WICON 2011, LNICST 98, pp. 501–510, 2012.

Providing QoS assurances to MANETs applications is difficult due to the lack of centralized control, node mobility, unreliable wireless channel and channel contention. Up to now, Admission control (AC) is one of the crucial components for providing QoS assurances. Additionally, a range of related mechanisms are required to make admission decisions.

The responsibility of AC is to estimate the state of the network resources and decide whether application data can be admitted without promising more resources. The key aspect of this problem is the collection of information about the available network resources and the performance of AC in MANET. Then according to the information collect, AC makes a decision whether the session should be admitted.

On the one hand, AC aims to admit as many sessions as possible, while utilizing the network's resources fully and efficiently. On the other hand, any inaccuracy in the admission decisions can result in the pledging of more resources than available, leading to false admissions. False admission usually results bad QoS and poor user experiences. In contrast, conservative decision causes the waste of network resources. AC should achieve a right balance between admission accuracy and network resource waste.

However, it is hard to get accurate information about the status of network and sessions' satisfaction. Existing metrics for admission control protocols are either QoS-related or admission decision related, like false rejection ratio, session admission ratio, false admission ratio, session completion and dropping ratios, etc. The existing metrics are surveyed in detail in Section 2 which has been highlighted in recent surveys [1], [2]. They were insufficient to evaluate the performance and the balance of AC, particularly with regard to evaluating the satisfaction of the session requirement and the network status offered.

We need new metrics to reflect the inherent balance of AC and the possible trade-off between the probabilities of false admissions and false rejections.

For the reasons mentioned above, this paper aims to address this issue while proposing fine-grained metrics for quantifying the balance of AC protocol.

The rest of this paper is organized as follows. Section 2 reviews the related works and covers the topic of some relevant background. Section 3 describes our design of new metrics for quantifying AC protocol performance and discusses the advantage and signification of these metrics. Section 4 represents a scheme to verify the design ideas. And finally, Section 5 concludes the whole paper and arranges the future work.

2 Related Works

Section 2.1 provides a brief list of the most prevalence QoS specification metrics, while metrics for AC performances are given and discussed in Section 2.2.

2.1 Metric for QoS Requirements Specification and Network Performance

Many metrics for specifying and measuring QoS were explained in [2], we give a recap of these metrics and also discuss the benefits and drawbacks. These QoS metrics can be used to define the MANET application requirements and evaluate the effect of AC in the system.

The requirements and AC performance are generally expressed by one or more of the following metrics:

- Minimum average throughput (bps) [3], [4], [5], [6].
- Propagation delay [4], [5], [7]. It is the *maximum* time difference between transmitting a packet by node and receiving this packet at the node, generally it is short.
- Maximum delay jitter bound[4], [7]. It can be defined as time gap difference between the maximum and minimum possible propagation delays across one link (including queuing delay) and the absolute minimum delay, which is determined simply by the cumulative propagation and packet transmission times A common alternative definition is the variance of the absolute packet delay[8].
- Maximum packet loss ratio (PLR) bound [4], [5. The maximum tolerable fraction of the generated data packets lost per route. The packet losses because of buffer overflow when congestion occurs, or in poor channel quality or after a node moves, the retransmission limit being exceeded, or due to a timeout while waiting for a new route to be discovered for the next hop.

In additions, other metrics of network resources (for example average processing time, consumed energy [9]) used to qualify AC performance.

Although these metrics can be use to reflect the AC performance ,they are subjective metrics and thus cannot be used to compare results from different networks, only for comparing results for different protocols operating in the same network with the same parameters and traffic load.

2.2 AC Protocol Performance Metrics

Admission control protocols in MANET is try to balance of the network resource abuse and pledging of too much resources. So metrics for AC should show this balance. On the one hand, metrics reflect the status of resource usage, such like the metric capacity utilization mentioned below; If AC admits as many sessions as possible, the network must be exploited fully; meanwhile, the usage of the network's resources should also be efficiently. On the other hand, any incorrect or not accurate admission control decision can lead to the pledging of more resources than are available.

If the network is under-utilized, and resources are sufficient, it will be easy to provide QoS assurance to admit sessions as the risk of congestion becomes impossible. The network is in low efficiency in terms of energy consumption and overhead and wastage of network resources. Rejecting a session which could have been served without degrading the QoS of previously admitted sessions may be termed a false rejection.

It is important of AC to hold an appropriate attitude. A positive attitude may lead to false admission and a too strict attitude would result in false rejection.

Thus, metrics can be categorized according to whether they measure the protocol's ability to utilize resources or its ability to satisfy applications' requirements. Although most AC protocol designers tend to demonstrate their protocols effectiveness by showing traces of QoS metrics, however this only shows the partial performance of the protocol. Some other metrics are as follows [1]:

Normalized Protocol Overhead (NPO): The average fraction of bytes of routing and AC packets and protocol headers, which are transmitted, normalized by the number of data bytes received at the destination. AC should achieve a balance between accuracy with overhead, which NPO can reflect [10].

Capacity Utilization (CU): The average fraction (over time) of the network's capacity that is utilized by data traffic. A large number of false rejections lead to a low capacity utilization. However, the capacity of wireless networks with random topologies can be difficult to quantify. Therefore, researchers often use the aggregate network throughput to reflect the level of capacity utilization, e.g. [6].

Session Admission Ratio (SAR): The fraction of requesting sessions that were admitted; this metric can be used as it is difficult to estimating capacity utilization efficiency. This metric reflects the number of data sessions admitted. It exposes the ability of the AC mechanism to estimate available resources and utilize them. For different protocols in the given traffic configurations and the same network, the AC protocol achieving a higher SAR, while not degrading the experienced QoS of data sessions, can be regarded a better one.

The weakness of this metric is that it depends on the offered traffic load and the absolute network capacity. It cannot be used to compare AC from different networks.

False Admission Ratio (FAR): The number of false admissions normalized by the number of admitted sessions or admission requests. Akin to the FRR, this metric is difficult to quantify. But some other methods are available for calculating the level FAR. One could measure the average proportion of packets [1]. In [6], the authors propose a method that FAR is quantified by an "actual network throughput minus the total throughput promised to admitted sessions" metric. However, both the FAR and FRR metrics are also affected by conditions outside of the AC protocol's control, such as node mobility and wireless channel confliction.

False Rejection Ratio (FRR): The fraction of false rejections normalized by the number of rejected sessions or admission requests. In a real system, the FRR is difficult to quantify, since whether a rejection is deemed false or not depends on the instantaneous states of resources and a session's requirements. FRR cannot be calculated accurately in a real system as to collect global admission information. It can only be used in simulation.

Session Completion and Dropping Ratios (SCR/SDR): The ratio of the number of data sessions completed to the application's satisfaction, or dropped before finished, to the number of sessions admitted into the network.

Session Completion Ratio (SCR): A fraction of the number of admitted sessions.

Intuitively, SDR = 1−SCR. the SCR and SDR can then easily be monitored and can partially reflect the accuracy of admission decisions and be used to monitor how well the protocol copes with these and can be used as a feedback of the AC[11]. However, these metrics are affected by factors outside of the protocol's control.

Also, there are subjective metrics like, numbers of admitted, flows rejection and blocking probability which can only for comparing results for different AC protocols performing in the same scheme and traffic load.

As stated above, some metrics are difficult to quantify, especially those related to resource utilization efficiency, some are not precise enough, for example, FAR, FFR, some are subjective and related with network and traffic load. Also, metrics for evaluating AC protocols should reflect this inherent balance, and possible trade-off between the probabilities of false admissions and false rejections.

3 New Metrics for Evaluating AC Performance

In this section, 3.1 not only describes the metrics briefly but also suggests the process of obtaining the metrics. Section 3.2 gives definitions of the metrics covering the session-level, local-level and system-level, also introduce two metrics deduced from the original metrics. Section 3.3 explains the meaning and benefits of these metric and describes the relationships between existing metrics in Section3.2.

3.1 Method to Obtain the Metrics

Our conclusions in Section 2 provided the motivation for us to design more exact and accurate metric to keep track of the effect of AC decision. The basic of our design is to monitor the data transfer stage and check whether the transfer state met the QoS requirements of the sessions in each time interval t_c during the transfer process. As illustrated in Fig.1.

When new sessions are admitted, they start the data transfer phrases.

Firstly, subdivide the data transfer stage into equal time intervals, a constant time interval is set as t_c which depends on how long it take to get the current QoS states.

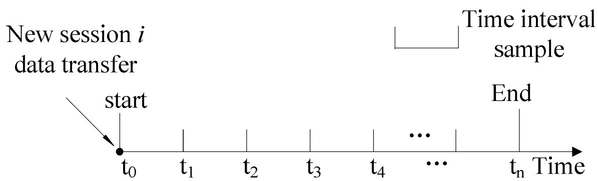

Fig. 1. Process of getting a metric

Secondly, collect the transfer status of the sessions in each time interval to see if the network performance reaches the demanded QoS.

The QoS requirements and experienced QoS during t_c time interval can be used to define the interval successful and failed conditions, for example, the specific QoS goal of the session is pre-defined by means of a set $\{Br, Dr, Jr, Priority\}$, the variables Br, Dr, Jr and $Priority$ represent the bandwidth, delay, jitter and priority of the session requirements respectively. After observing the transfer state of t_c, for instance, from t_0 to t_1, we count and statistic QoS parameters and then examine each in turn, check if each requirement is fitted. If the entire QoS goal is served, all the requirements are satisfied during the time interval $[t_0, t_1]$, it is regarded as a successful interval, otherwise as a failed interval.

Note that the length of t_c must depend on how much time need to collect the experienced network QoS status.

At the end of the sessions, we add up the number of the success and failed intervals.

3.2 Session and System Satisfaction Metrics

After the observation, all time intervals are categorized into two (2) types: success, during the intervals, the transfer status met the session's QoS requirements; fail, during the interval, the transfer status cannot fulfill with the requirements due to lack of resources. The type of the interval type can be autonomously classified by observing the QoS status of the time interval.

The number of time interval in each category are represented as $f_{success}$ and f_{fail}. As a summation, for session i, $F_i = f_{success\ i} + f_{fail\ i}$, F_i represents the number of all the time intervals during data transfer phrase of the session i.

Assume that session i is admitted, if session i transfers the data very fluently and successfully, then $F_i = f_{success\ i}$, $f_{fail\ i} = 0$; else longer the values of f_{fail}, the worse the session transfer status. In other words, we can use the fraction of f_{fail} and F_i to quantify the extent of session i's QoS.

Session Satisfaction Ratio (SeSR)

In developing our metric, we first define the total number of unsatisfied intervals session S1 during the course of data transfer phrase T1:

We define ρ_i as the measure of session satisfaction rate:

$$\rho_i = \frac{f_{success\ i}}{F_i} = \frac{f_{success\ i}}{f_{success\ i} + f_{fail\ i}} \tag{1}$$

Then, the session's disappointment ratio is $1\text{-}\rho_i$.

System Satisfaction Ratio(SySR)

Grouping all the number of success and fail time intervals in all the sessions. We get the combined metric for system satisfaction ratio as:

$$\rho_{system} = \frac{\sum_{i=1}^{n} f_{success\ i}}{\sum_{i=1}^{n} F_i} \tag{2}$$

Then, the system disappointment ratio is $1 - \rho_{system}$.

Local Satisfaction Ratio (LSR)

As the topology structure in MANETs may be in irregularity and the satisfaction of the session may be different from area to area. We propose metric for local satisfaction ratio (LSR), for each session in the local session set L,

$$\rho_{\text{local}} = \frac{\sum_{j:j\in L} f_{\text{success } j}}{\sum_{j:j\in L} \text{F}_j} \tag{3}$$

Then the local disappointment ratio is $1 - \rho_{\text{local}}$.

The following describes two new probabilities related metrics deduced from the satisfaction metrics. They can be predicted using a simple linear model.

Probabilities of False Admission (PFA)

FA can be an average value of system disappointment ratio in the long run. Probabilities of false admission can be predicted by satisfaction ratios as there is a connection between PFA and SeSR:

$$\text{P}_{\text{FA}} = \sum_{i=1}^{\text{n}} \frac{f(\rho_i)}{\text{n}} \tag{4}$$

In formula (4), we have an assumption that n sessions are admitted by AC from start to end, besides f is a piecewise function:

$$f(\text{x}) = \begin{cases} 1, & \text{x} = 1 \\ 0, & \text{else} \end{cases} \tag{5}$$

When a new session comes, the possibility of false admission is can be predicted by analyzing the previous period of T length behavior of AC. We can use the black box modeling approach to establish a linear model, then to derive the linear equation that models the relationship between the time and the PFA,

$$\widehat{\text{P}}_{\text{predict}} = \beta\hat{t} + \hat{\varepsilon} \tag{6}$$

The variable t represents the time and P represents predict value of the possibilities of false admission.

After creating this simple linear regression model, it is given a data set $\{\text{t}_\text{m}, \text{P}_\text{m}\}_{\text{m}=0}^{\text{k}}$ of k statistical units. For each pair of$\{\text{t}_\text{m}, \text{P}_\text{m}\}$, P_m is calculated for the prediction of PFA at the time of t_m.

In the model (6), we assume that the relationship between the dependent variable P_i and t_i is linear.

If an additional value of new time $\text{t}_{\text{i}+1}$ is then given, using this model we are be able to get a prediction of the value of $\text{P}_{\text{i}+1}$ very soon.

Probabilities of Completed Session (PCS)

Likewise, CS can be an average value of system satisfaction ratio in the long run. Probabilities of successful completed session can be predicted by satisfaction ratios as there is a connection between CS and SeSR:

$$\text{P}_{\text{PCS}} = 1 - \text{P}_{\text{FA}} = 1 - \sum_{i=1}^{\text{n}} \frac{f(\rho_i)}{\text{n}} \tag{7}$$

The function f is defined in formula (5). In the same manner, we can have a prediction of probabilities of successful completed session.

3.3 Discuss about the Metrics

The effect of the satisfaction ratio metrics for AC performance is relevant to the density and extent of congestion of the network.

The satisfaction ratio is related to several factors as following:

- Conservative or aggressive of the AC protocol attitude.
- Sufficient network resources or not.
- The number of the data sessions, that is, traffic load.
- Node mobility and interferences caused by changing of topology or new sessions.

These metrics have the following benefits:

- SeSR reflects the quality of transmission for one session. In comparison with FAR, the influence of node mobility and interference from neighbors can be analyzed quantitatively.
- If new admitted session causes harmful interference to the existing sessions. SeSR declines with the interference, which is beyond the reach old metrics FAR and FRR.
- SySR can quantify the entire state of the network; it is also related to the total number of data sessions and available network resources. It indicates the imbalance between supply and the demand of network resources.
- If the value of satisfaction ratio is very close to 100 percent, it indicates that there is either sufficient network resource or a too much strict AC decision.
- If the value of satisfaction ratio is at a low level, it suggests that AC decision is made over optimistically.

PFA can be used as a feedback for AC control to improve the trueness and precision of AC decision.

4 Feedback-Based Admission Control Design

This section suggests a feedback-based admission control design to enhance the accuracy of admission decision, also the combining with combination of existing AC protocols.

As mentioned in section 3.2, the satisfaction series of metrics can be the used for feedback of admission control mechanism as our fine-grained metrics can be obtained be observing and calculated.

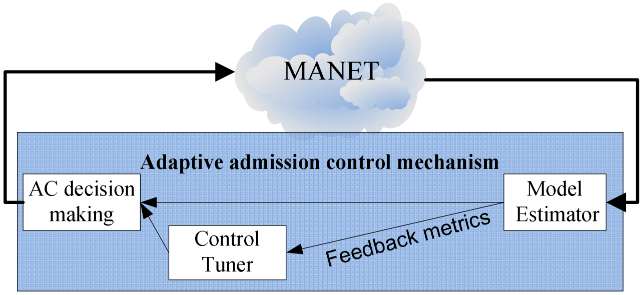

Fig. 2. Closed loop with feedback-based admission control

Model Estimator monitors the transmission state, and calculates the satisfaction ratio and possibility of false admission for each session or the entire MANET AC system. For a distributed AC protocol, session-level metrics are more suitable to be feedback parameter, for centralized one, system-level or local-level is more suitable. Control Tuner keeps automatically fine turns the received satisfaction ratios from Model Estimator and makes adjustments for AC decision making. Fine adjustments to precise the AC decision. Thus, the admission control mechanism can obtain better QoS and avoid congestion in MANET.

The feedback-based AC algorithm will consist of three stages: In the first one is the identification stage, the network identifies the quality, criteria of users that have not specified their requirements and, translates them into QoS metrics; The second stage is the probing stage or resource estimating stage, AC protocol estimates the current status of the network resources and calculates the value of PFA; Finally, in the decision stage, the AC searches and makes the decision according to both the state of the network resources and the value of PFA.

As this feedback-based design is independent with the routing protocols in MANETs, although there are the various behavior of existing AC, AC coupled with routing and without routing protocols, stateless and stateful admission control, distributed and centralized admission control, if the appropriate metrics is chosen as the feedback parameters. Our design can combine with these existing AC smoothly.

The above scheme can be implemented by a cross-layer approach, including an adaptive feedback scheme and admission scheme to provide information about the network status and the possibilities of false admission.

5 Conclusion and Future Work

This paper presents metrics for quantifying the satisfaction ratio of both the data sessions and the MANET with AC protocol, by monitoring the data transfer stage closely to get the number of time interval fail to meet the requirement, then by using existing metrics and values, returns a value along a linear trend, that is the pre-estimate of probabilities of false admission and successful completed transfer. Analysis shows that these new metrics are fine-gained and have a close relation with the existing AC performance metrics.

Also, we propose a feedback-based admission control design, in which, false admission ratio is predicted and used as the feedback parameter.

Further, as our future work, the design of feedback of admission control should be implemented to verify the accurateness of the satisfaction related metrics and the performance of the AC protocol both in a simulation system and real MANET environment. Beside, the predictions for false admission and successful completed session can be optimized by learning from the simulation experiences.

Acknowledgments. This work is supported by the National Science Foundation of China under Grant No. 61073076, Science and Technology on Information Transmission and Dissemination in Communication Networks Laboratory under Grant No. ITD-U10001, and Beihang University Innovation & Practice Fund for Graduate. The authors would like to thank great support.

References

1. Hanzo, L., Tafazolli, R.: Admission control schemes for 802.11-based multi-hop mobile ad hoc networks: a survey. IEEE Communications Surveys & Tutorials (2009)
2. Hanzo-II, L., Tafazolli, R.: A Survey of QoS routing solutions for Mobile Ad hoc Networks. IEEE Communications Surveys & Tutorials 9(2), 50–70 (2007)
3. Haitao, Z., et al.: A Soft Admission Control methodology for wireless Ad-Hoc networks: Evaluating the impact on existing flows before admission. In: 7th International Symposium on Communication Systems Networks and Digital Signal Processing, CSNDSP 2010 (2010)
4. Statovci-Halimi, B.: Adaptive admission control for supporting class-based QoS. In: 6th EURO-NF Conference on Next Generation Internet, NGI 2010 (2010)
5. Zhang, S., Yu, F.R., Leung, V.C.M.: Joint connection admission control and routing in IEEE 802.16-based mesh networks. IEEE Transactions on Wireless Communications 9(4), 1370–1379 (2010)
6. Yang, Y., Kravets, R.: Contention-Aware Admission control for ad-hoc networks. IEEE Transactions on Mobile Computing 4(4) (2005)
7. Hanzo II, L., Tafazolli, R.: QoS-Aware Routing and Admission Control in Shadow-Fading Environments for Multirate MANETs. IEEE Transactions on Mobile Computing 10(5), 622–637 (2011)
8. Bashandy, A.R., Chong, E.K.P., Ghafoor, A.: Generalized quality-of-service routing with resource allocation. IEEE Journal on Selected Areas in Communications 23(2), 450–463 (2005)
9. Saxena, N., Tsudik, G., Jeong, H.Y.: Efficient Node Admission and Certificateless Secure Communication in Short-Lived MANETs. IEEE Transactions on Parallel and Distributed Systems 20(2), 158–170 (2009)
10. Kone, V., Nandi, S.: QoS Constrained Adaptive Routing Protocol For Mobile Adhoc Networks. In: 9th International Conference on Information Technology, ICIT 2006 (2006)
11. Hongwei, L., Xinbing, W., Hsiao-Hwa, C.: Adaptive Call Admission Control for Multi-Class Services in Wireless Networks. In: IEEE International Conference on Communications, ICC 2008 (2008)