A QoS balancing model for Mobile Ad hoc Networks

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Abstract: -Quality of Service (QoS) provision is required for MANETs in recent years to support the rapid growth of video in mobile traffic. In spite of numerous QoS routing protocols, litter literature, it is observed, discusses about the QoS balancing model with several QoS metrics considered simultaneously, which is realistic in real applications, due to various units and attributes of QoS metrics. A new model, denoted by SAW-AHP, which is a combination of Simple Additive Weighting (SAW) and Analytic Hierarchical Process (AHP), is proposed in this paper to balance the competing QoS metrics. Despite of different units and attributes of diverse QoS metrics, SAW-AHP is able to rank the alternative routing protocols reliably and consistently by considering the relative preference of QoS metrics which is neglected by much literature.

Key words: -Mobile ad hoc network; Routing Protocol; QoS; SAW-AHP; Mobile traffic; Simulation

1 Introduction

A mobile ad hoc network (MANET) is an autonomous system of mobile nodes that are free to move about arbitrarily. The possibility of establishing such networks in places such as disaster relief sites and conference rooms, which are characterized by lack of prefixed infrastructure, justifies the development of MANETs. QoS provision was not considered initially in MANETs. However, with the rapid growing of video traffic which exceeds 50% of mobile traffic [1], QoS guarantee becomes necessary, leading to the existence of a collection of QoS-aware routing protocols [2][3].

However, a number of QoS metrics should be guaranteed simultaneously in real applications and some algorithms, it is observed, are able to support only part of QoS metrics on the cost of others, resulting in the random selection of protocols in MANETs. In this paper, a novel QoS metrics balancing model, denoted by SAW-AHP, which is a combination of the Simple Additive Weighting (SAW) [4] and the Analytic Hierarchical Process (AHP) [5], is proposed to balance QoS requirements by considering the relative importance of different QoS metrics which is neglected by much literature. Extensive simulations are performed to validate the efficiency as well as reliability of the SAW-AHP model. For simulation, version 2.32 of the well-known open-source software NS-2 is used. This paper is organized as follows. Section 2 discusses the problems after simulations. The third part provides the problem solution method and the final section concludes this paper.

2 Problem Formulation

The network performance of several mobile terminals (MTs), which share a common access point to access the Internet, as shown in Fig.1, is studied as an example for the SAW-AHP model. The simulation configurations as well as results are itemized in Table 1 and Table 2 respectively.

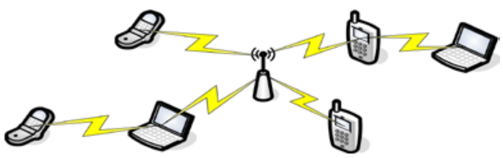

Fig.1 Simulation scenario

Table 1. Simulation parameters

Parameter	Description
Simulation time	3000s
Simulation runs	50
Number of nodes	32
Node mobility pattern	Random Way Point Model
Transmission range	25m
Routing protocol	DSDV and DSR
Traffic load	2 streams
Topology	100m*100m

Table 2. Simulation results

	PDR (%)	Delay (ms)	Jitter (ms)	Thrput (Mb/s)	EC (J/pkt)
DSDV	94.7	1.98	2.41	3.68	0.73
DSR	99.1	2.68	2.91	3.38	0.214
PDR: packet delivery ratio; Thrput: throughput; EC: energy cost					

2.1 Simulation results and analysis

As shown in Table 2, DSR outperforms DSDV in terms of packet delivery ratio and energy cost. Three factors contribute to the success of DSR. To begin with, DSR initiates the route discovery mechanism only when necessary, avoiding the use of stale routes as well as periodic routing information broadcast. Secondly, if a link breaks down in the data transmission process, the upstream node may buffer the lost packets and activate the local link repair mechanism which increases the number of data packets that are able to be delivered. Last, but not the least, DSDV broadcasts route information packets periodically and those packets may collide with data packets.

However, DSDV outperforms DSR in other three metrics, delay, jitter and throughput. The key reason for this is the proactive nature of DSDV. DSDV is able to establish route much more quickly by searching routing tables which is updated periodically. Instead, DSR initiates a route discovery process on demand which takes more time.

2.2 Problem statement

For a network operator who strives to offer reliable packet delivery service, DSR is better a solution compared to DSDV. On the contrary, for a time sensitive application, DSDV is preferred. However, when the number of QoS-metrics increases, just as in many real applications, the problem becomes much more complicated [6].

3 Problem Solution

The proposed SAW-AHP model involves mainly two steps as shown in Fig.2.

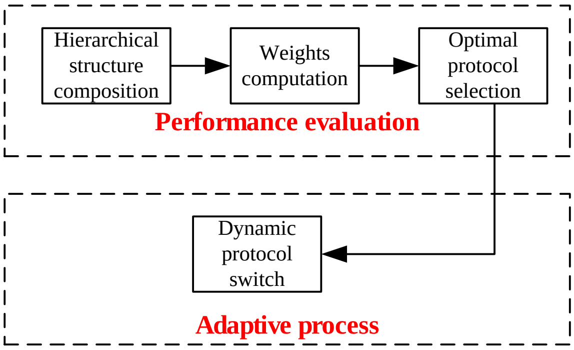

Fig.2 SAW-AHP diagram

3.1 Performance evaluation

The performance evaluation process can be further divided into three steps and the first step is to decompose the decision problem into a hierarchy structure, composed of an objective layer, a criteria layer and an alternative layer so that a hard problem can be more easily understandable.

3.1.1 Hierarchy structure

The objective in this paper is to balance five QoS metrics and thus find the optimal routing protocol given the preference of a number of QoS metrics which are treated as criteria. For simplicity but without loss of generality, two alternatives DSDV, which is a proactive routing protocol, and DSR, which is a reactive protocol are selected. Fig.3 shows the hierarchy structure with three layers, the objective layer, criteria layer and alternative layer.

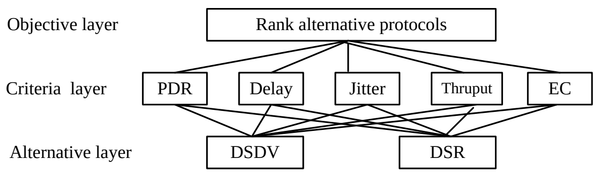

Fig.3 Hierarchy structure

3.1.2 Weights computation

Once the hierarchy is built, the decision makers compare elements in a pair-wise fashion with pre-defined rules based on which the comparison matrices are obtained.

3.1.2.1 Weight for QoS metric

A decision maker is assumed to be able to compare any two elements, say E_i and E_j, at the same level of the hierarchy structure and provide a numerical value e_{ij} according to his/her preference, $e_{ij} > 0$ for any i=1,2,…,n and j=1,2,…,n. The reciprocal property e_{ji}=1/ e_{ij} holds. The fundamental scales for pair-wise comparison could serve as a good basis and they are itemized in Table 3.

Table 3. Importance and definition

Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one element over another
5	Strong importance	Experience and judgment strongly favour one element over another
7	Very strong importance	One element is favoured very strongly over another;
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation
Intensities of 2,4,6 and 8 can be used to express intermediate values.		

Prior to obtaining the pair-wise comparison matrix for criteria, several assumptions are made for the relative importance of criteria in this paper. They are as follows: (I)Packet delivery ratio is moderately more important than delay; (II)Packet delivery ratio is moderately more important than jitter; (III)Packet delivery ratio and throughput are equally important; (IV)Packet delivery ratio is moderately more important than energy cost; (V)Delay and jitter are equally important; (VI)Delay and energy cost are equally important; (VII)Jitter and energy cost are equally important; (VIII)Throughput is moderately more important than delay; (IX)Throughput is moderately more important than jitter; (X)Throughput is moderately more important than energy cost.

One thing to note is that these parameters are application dependent and the choices here are for a specific application scenario. According to Table 3, the above 10 assumptions lead to the comparison matrix for criteria as follows

$$C=\left(\begin{array}{cccccc} & PDR & Delay & Jitter & Thrput & EC \\ PDR & 1 & 3 & 3 & 1 & 3 \\ Delay & 1/3 & 1 & 1 & 1/3 & 1 \\ Jitter & 1/3 & 1 & 1 & 1/3 & 1 \\ Thrput & 1 & 3 & 3 & 1 & 3 \\ EC & 1/3 & 1 & 1 & 1/3 & 1 \end{array}\right) \quad (1)$$

where *PDR*, *Thrput* and *EC* denote packet delivery ratio, throughput and energy cost respectively.

There are several methods to derive weights from a comparison matrix of which Geometric Mean Method (GMM) is a straight forward and reliable alternative [7]. In GMM, the normalized weight is computed firstly via

$$\omega_i = \left[\prod_{j=1}^{n}(a_{ij})^{\frac{1}{n}}\right] / \left[\sum_{i=1}^{n}\left(\prod_{j=1}^{n}(a_{ij})^{\frac{1}{n}}\right)\right] \quad (2)$$

where a_{ij} ($i,j=1,2,\ldots,n$) denotes the value of ij'th elements in comparison Matrix (1) and n is number of elements in the row.

Combining Eq. (2) with Matrix (1), the normalized weights for criteria are obtained in Table 4.

Table 4. Normalized weights for criteria

Criteria	PDR	Delay	Jitter	Thruput	EC
Weight	0.333	0.111	0.111	0.333	0.111

As observed, the weights for packet delivery ratio and throughput are equal, indicating the same importance of those two metrics. Delay, jitter and energy cost have the same weight which accounts for one third of that for packet delivery ratio, revealing that they are less important compared to packet delivery ratio. Qualitatively, a protocol that has a better performance in terms of packet delivery ratio and throughput is more likely to be selected.

A decision maker may give inconsistent judgments for the comparison matrix and therefore SAW-AHP is designed with capability of measuring the consistency based on the idea of cardinal transitivity. A matrix M is consistent if and only if $a_{ik}\times a_{kj}= a_{ij}$, where a_{ij} is the ij'th element in Matrix (1). However, this condition can rarely be satisfied in practice, especially in scenarios with a large number of criteria or alternatives. The violation level of consistency changes with person or context. In SAW-AHP, a metric Consistency Ratio (*C.R.*), developed by Satty [5], is employed to indicate the extent to which the consistency is violated as follows

$$C.R. = \begin{cases} \left(\frac{1}{n}\sum_{i=1}^{n}\frac{(C\omega)_i}{\omega_i} - n\right)/[(n-1)\times(R.I.)] & n>2 \\ 0 & n=1,2 \end{cases} \quad (3)$$

where C and ω_i denote the pair-wise comparison matrix and weight for the i'th element respectively, n represents the number of elements and *R.I.* is the random index of a pair-wise comparison matrix that depends on the number of elements in the matrix as itemized in Table 5.

Table 5. Random inconsistency index (R.I.)

Number of elements	3	4	5	6	7
Random Index (R.I.)	0.58	0.90	1.12	1.24	1.32

The *C.R.* of Matrix (1) equals 0, indicating that Matrix (1) is consistent.

3.1.2.2 Weight for alternatives

Instead of using scales in [5], simulation results obtained in Table 2 are employed to construct the pair-wise comparison matrices for alternatives for the sake of accuracy. However, the attributes and units of metrics are different. Table 6 summarizes the attributes of metrics in this paper. As seen, two metrics, packet delivery ratio and throughput, are grouped into the "the larger the better" category while the other three metrics, delay, jitter and energy cost, are allocated to the "the smaller the better" category.

Table 6. Metric and attributes

Metric	PDR	Thruput	Delay	Jitter	EC
Attribute	the larger the better		the smaller the better		

In SAW-AHP, The value of the corresponding element in the pair-wise comparison matrix for alternatives equals

$$a_{ij}=d_i^{norm}/d_j^{norm} \tag{4}$$

where $d_i^{norm}=d_i/\max\{d_i\}$ for metrics that are "the larger the better" and $d_i^{norm}=\min\{d_i\}/d_i$ for the parameters that are "the smaller the better".

Table 7. Weights for alternatives

Criterion	Weights				
	PDR	Delay	Jitter	Thruput	EC
DSDV	0.489	0.575	0.547	0.521	0.227
DSR	0.511	0.425	0.453	0.479	0.773

Table 7 itemizes the weights for alternatives under different metrics. As seen, DSR has larger weights in terms of packet delivery ratio and energy cost, indicating its better performance over DSDV in those two metrics. On the contrary, the weights for DSDV exceed those for DSR in three other metrics, revealing DSDV's better performance in delay, jitter and throughput. Since there are only two elements in the comparison matrices for alternatives, those matrices are consistent.

3. Synthetic weights

The final step is to synthesize the weights for criteria via

$$s\omega_j=\sum_{i=1}^{n}c_i\omega_{ij}\,(i,\,j=1,\ldots,n) \tag{5}$$

where $s\omega_j$ denotes the synthetic weights for the j'th alternative, c_i symbolize weights for the i'th metric and ω_{ij} represents the weight for the j'th alternative under the i'th metric. The alternative with the largest synthetic weight is considered to the optimal one.

Table 8. Synthetic Weights

Protocol	Synthetic weight	Ranking order
DSDV	0.49	DSR>DSDV
DSR	0.51	

As shown in Table 8, the weight of DSR is larger than DSDV. Therefore, DSR is preferred in this case.

3.2 Adaptive process

Based on the ranking order, DSR is selected in this case. Four sets of simulations are carried out as shown in Fig.4 to validate the reliability as well as efficiency of the adaptive process.

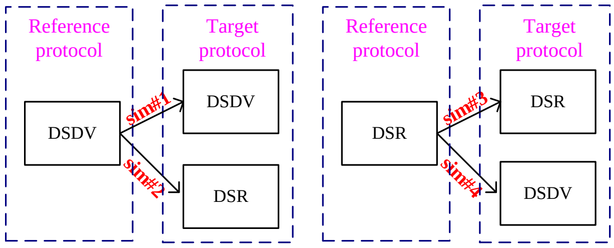

Fig.4 Simulations for validation

As shown, both sim#1 and sim#3 continue to employ the same protocol whereas the other two switch to a different protocol. Sim#1 and sim#2 are combined to determine the effect of switch from DSDV to DSR whereas sim#3 and sim#4 are combined to reveal the effectiveness of the switch to DSDV. The results are itemized in Table 9.

Table 9. Simulation results

metric	sim#1	sim#2	sim#3	sim#4
PDR (%)	94.7	99.1	99.1	94.8
Delay (ms)	1.98	2.68	2.68	1.99
Jitter (ms)	2.41	2.91	2.91	2.41
Thruput (Mb/s)	3.68	3.38	3.38	3.68
EC (J/pkt)	0.73	0.214	0.214	0.72

3.3 Performance Improvement Ratio

A metric, the performance improvement ratio denoted by *PIR*, is developed to specify the level of difference between two alternatives under certain metrics. *PIR* is defined as the quotient of the difference between the reference and target protocols for a value of the reference protocol. For metrics that are "the larger the better", $PIR_{ref\text{-}tar}$ is computed via

$$PIR_{ref-tar} = \frac{P_{\text{target}} - P_{\text{reference}}}{P_{\text{reference}}} = \frac{P_{\text{target}}}{P_{\text{reference}}} - 1 \quad (6)$$

where P_{target} and $P_{reference}$ denote the performance of the target and reference protocols respectively. For "the smaller the better" metrics, $PIR_{ref\text{-}tar}$ is

$$PIR_{ref-tar} = \frac{1/P_{\text{target}} - 1/P_{\text{reference}}}{1/P_{\text{reference}}} = P_{\text{reference}}/P_{\text{target}} - 1 \quad (7)$$

A positive *PIR* suggests the performance improvement while a negative one reveals the deterioration. PIRs may be aggregated by considering the weights for metrics in an application via

$$AIR_i = c_i \times PIR_i$$

(8)

where AIR_i denotes the aggregated improvement ratio for the i'th metric and c_i denotes the weight for i'th metric. *AIR* reflects the impact of performance improvement/deterioration of a metric on the overall QoS satisfaction. AIRs are synthesized to obtain the synthetic improvement ratio index (*SIRI*)

$$SIRI = \sum_{i=1}^{n} AIR_i \quad (9)$$

A positive *SIRI* is desired since it indicates system improvement when a target protocol is selected. On the contrary, a negative *SIRI* reveals performance deterioration if the target protocol is selected.

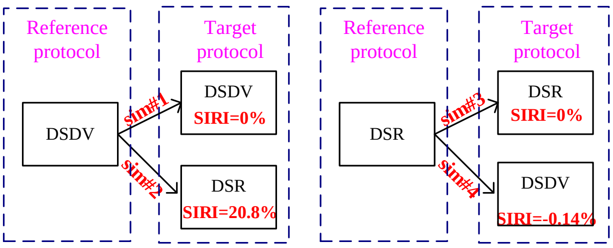

Fig.5 *SIRI* results

As seen in Fig.5, a positive *SIRI* is achieved which demonstrates the effectiveness of the protocol switch from DSDV to DSR. On the contrary, when DSDV replaces the original DSR protocol, the overall performance deteriorates. Therefore, it is concluded that DSR is more suitable for the case of 2 traffic streams, which is identical with results in Table 8.

4 Conclusion

In spite of various attributes and units for different QoS metrics, the proposed SAW-AHP is able to balance competing QoS metrics and thus rank alternative protocols DSDV and DSR efficiently and reliably. Based on the performance evaluation results, the system is able to switch to the optimal protocol adaptively. Extensive simulations show that the performance of the whole network may improve as much as 20.8% by adopting the SAW-AHP model. Despite only one case being studied in this paper using the SAW-AHP method, it is generic to other cases with different QoS requirements.

5. Future work

The SAW-AHP model is appropriate for scenarios where the decision maker is certain about his/her preference on the performance metrics and only the average value is considered. In the future, the SAW-AHP model will be fuzzified to incorporate the standard deviation of simulation results as well as the uncertainty of the decision maker.

Acknowledgement

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