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A Performance Evaluation Model for Mobile Ad Hoc Networks and Sensor Networks

[1,*] Heng LUO, [1] Jianping CHEN, [2] Ai-Huang GUO, [1] Ning WANG, [1] Yu TANG

[1] Suzhou University of Science and Technology, No. 1, Kerui Road, Suzhou, 215000, China
[2] Tongji University, 4800 Caoan Road, Shanghai, 201804, China
[*] Tel.: 8613862404231, fax: +8651269573006
[*] E-mail: luoheng1981@163.com

Received: 16 January 2014 /Accepted: 28 February 2014 /Published: 31 March 2014

Abstract: Potential applications in areas such as military sites and disaster relief fields that are characterized by absence of prefixed infrastructure justify the development of mobile ad hoc networks (MANETs) and wireless sensor networks (WSNs). However, unfavorable wireless links and dynamic topology are still challenging, leading to the proposal of a collection of routing protocols for MANETs and WSNs. Nevertheless the performance of algorithms may vary with deployment scenario due to the application dependent philosophy behind algorithms. In this paper, the performance evaluation problem for MANETs and WSNs is investigated and a novel performance ranking model, termed AHP-SAW, is proposed. For simplicity but without loss of generality, the performance of two routing protocols DSDV and DSR are studies based on which ranking results are provided. Extensive simulations show that an overall 37.2 %, at most, gain may be achieved based on the AHP-SAW model. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Mobile ad hoc network, Wireless sensor networks, Performance evaluation, AHP-SAW, Routing.

1. Introduction

Mobile ad hoc networks (MANETs) [1] are composed of nodes that are able to move arbitrarily. Each node serves as terminal and relay at the same time so that the network may operate autonomously. To date, MANETs have already been deployed in many fields.

Vehicular communication is an area where MANETs gain wide popularity. The FleetNet project [2] collects and shares location-dependent information for passengers. The European Project CarTALK [3] focuses on warning messages distribution when high traffic density, congestion, or dangerous road surfaces are detected in order to prevent potential traffic accidents.

Besides vehicular communication MANETs have also been implemented in the fields of environment monitoring. L. Laffea [4] established a MANET in a forest to study the movement of CO_2 so that the impact of forest-atmosphere CO_2 exchange can be estimated more accurately. The PermaSense project [5] depended on a MANET to investigate the relationship between climate change and rock fall in permafrost areas.

Benefits are also obtained in the civil engineering through MANETs. S. Kim [6] deployed a MANET on the south tower of the Golden Gate Bridge in order to measure the ambient structural vibrations reliably without interfering with the normal operation of the bridge. A structure-aware self-adaptive system (SASA) [7] based on a MANET is realized to rapidly

Article number P_1911

detect the collapse area in a coal mine, which makes mining safer.

In September 2007, the TerraNet AB Company [8] implemented a mobile ad hoc network which allows phone calls and data to be forwarded between participating handsets without cell sites. P. Sikka [9] maintained a MANET on a farm to provide soil moisture profiles at varying depth and animal movement tracking so that the cost of managing farms is reduced. One Laptop per Child (OLPC) [10] was a project, targeting at the creation of educational opportunities for the world's poorest children by providing each child with a laptop. These laptops are organized through mobile ad-hoc networking which allows students to access the Internet and participate in collaboration.

Despite of successful applications of MANETs in many fields that are characterized by absence of prefixed infrastructure, unfavorable conditions such as dynamic topology, time-dependent wireless links and limited energy are still challenging for such networks.

Routing, because of its importance, has always been the research focus since the introduction of MANETs. Compared to wire networks, MANETs has unique characteristics and therefore both distance vector and link state routing algorithms, which behave quite well, can not be mapped directly into MANETs. An Internet Engineering Task Force (IETF) work group was set up to deal with routing problems, resulting to existence of a series of routing algorithms. For the sake of space limitation only two of them, a typical proactive one and a reactive one, are introduced briefly in this paper.

DSDV [11] is a typical proactive routing protocol in which each node has to maintain a routing table for all available destinations. Routing updates are broadcast periodically. DSDV relies on a sequence number to indicate the freshness of the corresponding item to guarantee loop-freedom. When a route breakage between two nodes, say A and B, is detected by node A, it increases the corresponding sequence number and sets the distance to node B as infinite and this information will be further broadcasted.

In DSDV, the routing information broadcasts introduce a large number of control packets which increases the overhead. At the same time, it takes some time before a route can be used, the so called the convergence time [12]. In wired networks where the topology is comparatively stable, this convergence time is minor and it can be neglected. However, in a network where topology changes rapidly, the convergence time is sufficiently long that there will likely be a lot of dropped packets.

DSR is a reactive protocol which establishes routes on demand [13]. It initializes a route request process when a route to the destination is not known in the route cache. Up on receiving a route request packet (RREQ) packet, intermediate nodes either generate a route reply packet (RREP) while it caches the corresponding route or it adds its own address to the RREQ and forwards the RREQ until it reaches the destination or the packet live time expires. As long as bidirectional links exist, the reverse path will be used when the destination or intermediate node doesn't have a route to the source in the cache. In the case of a route breakage, an error packet is generated by the node which detects it and the corresponding item in the route cache is erased.

Compared to DSDV, DSR doesn't use periodic broadcasts and thereby reduces routing overhead, saves energy and partly eases network congestion. However, each data packet carries routing information in DSR, increasing the overhead.

Table 1 compares the performance of DSDV and DSR with other three well-studied protocols. As seen, all of them are loop free, avoiding the waste of limited resources in MANETs. DSDV and OLSR are two proactive protocols and more energy and bandwidth are consumed for routing information advertisements. DSDV and OLSR are more suitable for slowly changing networks in which it takes less time to converge. DSR is the only protocol that supports unidirectional links. Although energy is of great importance for many mobile devices, it is not considered in all protocols. None of the protocols above are adaptive, indicating that they do not contain any smart routing schemes. Meanwhile, it is observed that QoS issues are not considered in any of those protocols.

Table 1. Comparison of protocols for MANETs.

Property	Protocol				
	DSDV	**DSR**	**AODV [14]**	**TORA [15]**	**OLSR [16]**
Loop-free	Yes	Yes	Yes	Yes	Yes
Reactive	No	Yes	Yes	Yes	No
Unidirectional link support	No	Yes	No	No	No
Power conservation	No	No	No	No	No
Adaptive	No	No	No	No	No
QoS support	No	No	No	No	No

Moreover it is observed current routing algorithms are able to support only one or two performance metrics simultaneously on the cost of others which is contrary to the requirements of real applications where several performance metrics are demanded simultaneously. What's worse, the performance of protocols may vary with application scenarios as shown in Table 2. Therefore, the network operator can only select the routing algorithm randomly.

The absence of a performance evaluation model, it is argued, results in the random selection of routing protocols. Generally speaking, there are three methods to evaluate the performance of a given routing protocol, namely practical implementation [20], mathematical derivation [21] and simulation [22]. Results achieved by practical implementation are credible but they are scenario related and can't be repeated. Mathematical derivation is comprehensive, but it is complicated and assumptions in the mathematical model degrade the credibility. Simulation offers the ability to evaluate multiple systems in a number of scenarios in a repeatable manner. However, just as with mathematical modeling, modeling assumptions may decrease the credibility of the results.

Table 2. Performance comparison.

Protocol	Metric	Results	Conditions
AODV DSR DSDV [17]	PDR	AODV > DSR > DSDV	PT∈ [0,200]s
		DSDV<AODV<DSR	PT∈ [25,80]s
	Delay	DSDV<AODV<DSR	PT∈ [120,160]s
		DSR=DSDV<AODV	PT∈ [160,200]s
AODV DSR OLSR [18]	PDR	OLSR>AODV>DSR	NS∈ [0,6] m/s
		AODV>DSR >OLSR	NS∈ [6,20] m/s
	Delay	AODV>DSR >OLSR	NS∈ [0, 6] m/s
		DSR>AODV>OLSR	NS∈ [6,20] m/s
	PDR	AODV>DSR >OLSR	TV∈ [0,35] streams
		OLSR>AODV>DSR	TV∈ [35, 100] streams
	Delay	AODV>DSR >OLSR	TV∈ [8, 15] streams
		DSR>AODV>OLSR	TV∈ [25,100]streams
AODV DSR, TORA DSDV [19]	PDR	DSR>AODV >TORA>DSDV	PT∈ [0,300]s
		DSR>AODV >DSDV>TORA	PT∈ [300,1000] s
PT: pause time (Random Waypoint model) NS: node speed TV: traffic volume			

In this paper, the difficulty in choosing optimal routing protocol is investigated firstly in this paper followed by proposal of a vigorous mathematical model, termed AHP-SAW, which is a combination of Analytic Hierarchical Process (AHP) [23] and Simple Additive Weighting (SAW) [24]. AHP-SAW depends on mathematical derivation as well as simulations to evaluate routing protocols by considering the relative importance of performance metrics which are neglected by much literature. Extensive simulations are presented to validate the efficiency and reliability of the AHP-SAW model.

For simplicity but without loss of generality, DSDV, a typical proactive routing protocol, and DSR, a typical reactive routing protocol, are selected as two alternative protocols for comparisons. In this way, the efficiency of the proposed adaptive algorithm can be observed clearly. However, the results can be applied to other cases directly.

This paper is organized as follows. Section 2 outlines the problems via simulations. The third section introduces the AHP-SAW model. Section 4 validates the AHP-SAW model and the final part concludes this paper and discussed about the future work.

2. Simulation and Problem Statement

2.1. Simulator

To date, a number of simulation tools (e.g., NS-2 [25], GloMoSim [26], OPNET [27], QualNet [28] and MATLAB [29]) have been developed for wireless and ad hoc network simulations among which NS-2 is a widely used one. In addition to the flexibility as well as convenience, the open source property also contributes to the success of NS-2. The role for NS-2 is so important in the research community of mobile ad hoc networks that it has become the de-facto reference simulator [30]. Since only a small network (30 nodes) is simulated in this thesis, the problem of scalability for NS-2 can be ignored. Therefore NS-2 is applied in this paper.

2.2. Simulation Configurations

The performance of a typical mobile ad hoc network in the university campus where several laptops/mobile phones share a common access point to access the Internet, as shown in Fig.1, is investigated as an example for the AHP-SAW model. The simulation configurations and results are itemized in Table 3 – Table 6 respectively. The simulation time lasts for 3000 s for each measure to avoid the initialization bias. 50 independent simulation runs are carried out and the final results are averaged. 2, 6 and 10 streams are added into the network, simulating different traffics patterns.

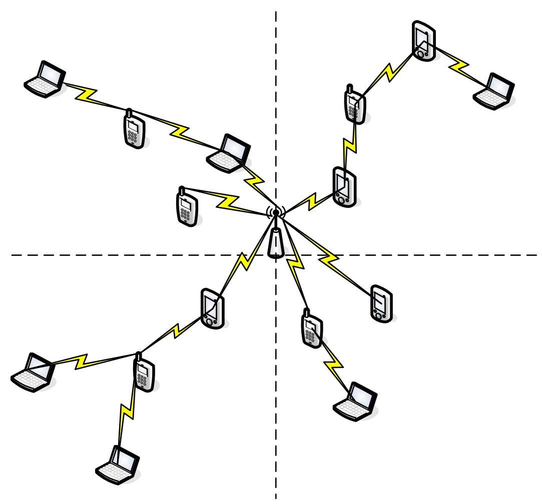

Fig. 1. Simulation scenario.

Table 3. Simulation parameters.

Parameter	Description	Parameter	Description
Simulation time	3000s	Transmission protocol	TCP
Simulation runs	50	Routing protocol	DSDV and DSR
Number of nodes	32	MAC layer protocol	802.11
Node mobility pattern	Random Way Point model	Propagation model	Rayleigh Fading
Mobility speed	Uniformly [0, 1.5] m/s	Traffic load	2,6,10 streams
Transmission range	25 m	Topology	100m×100m

Table 4. Simulation results (2 streams).

	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					

Table 5. Simulation results (6 streams).

	PDR (%)	Delay (ms)	Jitter (ms)	Thrput (Mb/s)	EC (J/pkt)
DSDV	69.10	3.63	4.01	3.57	0.29
DSR	85.00	7.88	13.90	3.29	0.17
PDR: packet delivery ratio; Thrput: throughput; EC: energy cost					

Table 6. Simulation results (10 streams).

	PDR (%)	Delay (ms)	Jitter (ms)	Thrput (Mb/s)	EC (J/pkt)
DSDV	65.70	3.58	4.37	3.55	0.26
DSR	82.40	9.85	14.40	3.25	0.19
PDR: packet delivery ratio; Thrput: throughput; EC: energy cost					

2.3. Simulation Results and Analysis

As seen, the packet delivery ratio decreases due to the network traffic congestion as more traffic is involved. Similarly, energy cost becomes smaller with the traffic volume increase since more packets are transmitted and the overall energy consumption is reduced.

In contrast, the performance of MANETs in terms of both delay and jitter deteriorates when the number of traffic rises.

The throughput is comparatively stable in spite of marginal decrease as the number of traffic grows.

2.4. Problem Statement

In conclusion, DSR behaves better in terms of packet delivery ratio and energy cost in all three cases due to its on-demand nature, which avoids the use of stale routes as well as periodic routing information broadcast. On the contrary, DSDV outperforms DSDV in delay, jitter and throughput in all cases. The key reason is its proactive philosophy. DSDV is able to establish route much more quickly by searching routing table in the cache which is updated periodically. Instead, DSR initiates a route discovery process when necessary which consumes more time.

For a network operator who has time sensitive applications, DSR is better a solution compared to DSDV. On the contrary, for reliable packet delivery service, DSDV is preferred.

A sound solution, it is suggested, is to develop a performance evaluation method through which the operator may choose the optimal protocol dynamically for specific application scenarios.

3. SAW-AHP Model

The proposed performance evaluation AHP-SAW model involves three steps and the first one is to decompose the evaluation 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. One thing to note is that results in Table 4 – Table 6 are used in this section to compute the weights for alternatives.

3.1. Hierarchy Structure

The objective in this paper is to evaluate the performance of DSR and DSDV in MANETs with several performance metrics considered and rank them accordingly given the operator's preference of performance metrics which are regarded as criteria of a network operator. Fig. 2 shows the hierarchy structure with three layers, the objective layer, criteria layer and alternative layer.

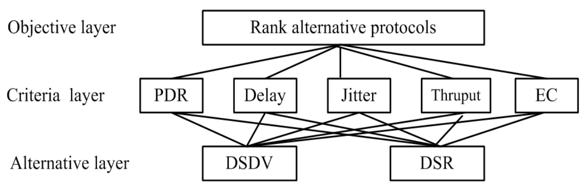

Fig. 2. Hierarchy structure.

3.2. Weight for Metrics and Alternative Protocols

The following step is to compute weights for both metrics and alternative protocols.

3.2.1. Weight for Metrics

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 rules for pair-wise comparison are listed in Table 7.

Table 7. The fundamental scales for pair-wise comparison.

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.		

Several assumptions are made in this paper 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 7, the above 10 assumptions lead to the comparison matrix for criteria as follows

$$C=\begin{pmatrix} & PDR & Delay & Jitter & Thrput & EC \\ PDR & 1 & 3 & 3 & 1 & 3 \\ Delay & 1/3 & 1 & 1 & 1/3 & 1 \\ Jitter & 1/3 & 1 & 1 & 1/3 & 1 \\ Thrput & 1 & 3 & 3 & 1 & 3 \\ EC & 1/3 & 1 & 1 & 1/3 & 1 \end{pmatrix}, \quad (1)$$

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 [30]. In GMM, the normalized weight is computed firstly via

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

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

Combining (2) with Matrix (1), the normalized weights for criteria are obtained in Table 8.

Table 8. Normalized weights for criteria.

Criterion	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 AHP-SAW 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 of the 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 AHP-SAW, a metric Consistency Ratio ($C.R.$), developed by Satty [23], is employed to indicate the extent to which the consistency is violated as follows

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

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 9. As long as C.R.≤0.1, the matrix is believed to be consistent [23]. The $C. R.$ of Matrix (1) equals 0 indicating that Matrix (1) is consistent.

Table 9. 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

3.2.2. Weight for Alternative Protocols

Instead of using scales in Table 7, simulation results obtained in Table 4 – Table 6 are employed to construct the pair-wise comparison matrices for alternatives for the sake of accuracy. It is impossible to make use of these results due to their different attributes and units. Table 10 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 10. Metrics 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 $d_i^{\text{norm}} = d_i/max\ \{\ d_i\ \}$ for metrics that are "the larger the better" and d_j norm $= min\{\ d_j\ \}/d_j$ for the parameters that are "the smaller the better". The comparison matrix for alternative are listed in Table 11 – Table 13.

Table 14 – Table 16 itemize the weights for alternatives under different metrics by applying Equation (2) to Table 11 – Table 13. 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.

Table 11. Matrix for alternative (2 streams).

Metrics	PDR	Delay	Jitter
Matrix	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 0.96 \\ DSR & 1.05 & 1 \end{pmatrix}$	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 1.27 \\ DSR & 0.83 & 1 \end{pmatrix}$	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 0.29 \\ DSR & 3.41 & 1 \end{pmatrix}$
Metrics	Thruput	EC	PDR: packet delivery ratio; Thruput: throughput; EC: energy cost
Matrix	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 1.09 \\ DSR & 0.92 & 1 \end{pmatrix}$	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 0.29 \\ DSR & 3.41 & 1 \end{pmatrix}$	

Table 12. Matrix for alternative (6 streams).

Metrics	PDR	Delay	Jitter
Matrix	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 0.81 \\ DSR & 1.23 & 1 \end{pmatrix}$	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 2.17 \\ DSR & 0.46 & 1 \end{pmatrix}$	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 3.47 \\ DSR & 0.29 & 1 \end{pmatrix}$
Metrics	Thruput	EC	PDR: packet delivery ratio; Thruput: throughput; EC: energy cost
Matrix	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 1.09 \\ DSR & 0.92 & 1 \end{pmatrix}$	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 0.59 \\ DSR & 1.71 & 1 \end{pmatrix}$	

Table 13. Matrix for alternative (10 streams).

Metrics	PDR	Delay	Jitter
Matrix	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 0.80 \\ DSR & 1.25 & 1 \end{pmatrix}$	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 2.75 \\ DSR & 0.36 & 1 \end{pmatrix}$	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 3.30 \\ DSR & 0.30 & 1 \end{pmatrix}$
Metrics	Thruput	EC	PDR: packet delivery ratio; Thruput: throughput; EC: energy cost
Matrix	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 1.09 \\ DSR & 0.92 & 1 \end{pmatrix}$	$\begin{pmatrix} & DSDV & DSR \\ DSDV & 1 & 0.72 \\ DSR & 1.38 & 1 \end{pmatrix}$	

Table 14. Weights for alternatives (2 streams).

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 15. Weights for alternatives (6 streams).

Criterion	Weights				
	PDR	Delay	Jitter	Thruput	EC
DSDV	0.448	0.685	0.776	0.520	0.368
DSR	0.552	0.315	0.224	0.480	0.632

As shown in Table 17, the weight of DSR is larger than DSDV in 2 streams. DSDV is preferred when traffic increases to 6 and 10 streams.

Table 16. Weights for alternatives (10 streams).

Criterion	Weights				
	PDR	Delay	Jitter	Thruput	EC
DSDV	0.444	0.733	0.767	0.520	0.420
DSR	0.556	0.267	0.233	0.480	0.580

3.3. Synthetic Weights

The final step of the SAW-AHP model is to synthesize the weights for criteria via

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

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 $i^{\prime th}$ metric. The alternative with the largest synthetic weight is considered to the optimal one.

Table 17. Synthetic weights.

Traffic volume	Protocol	Synthetic weight	Ranking order
2 streams	DSDV	0.49	①DSR②DSDV
	DSR	0.51	
6 streams	DSDV	0.53	①DSDV②DSR
	DSR	0.47	
10 streams	DSDV	0.54	①DSDV②DSR
	DSR	0.46	

4. Results Validation

4.1. Validation Model

Four sets of simulations sim#1, sim#2, sim#3 and sim#4 are carried out as shown in Fig.3 to validate the AHP-SAW model. As seen, 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 18 – Table 20.

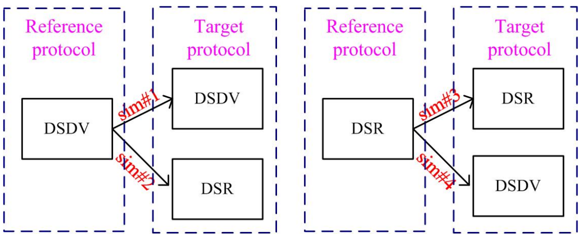

Fig. 3. Simulations for validation.

4.2. 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

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

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

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

Table 18. Simulation results (2 streams).

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

Table 19. Simulation results (6 streams).

Metric	sim#1	sim#2	sim#3	sim#4
PDR (%)	69.10	84.90	85.00	69.30
Delay (ms)	3.63	7.87	7.88	3.66
Jitter (ms)	4.01	13.90	13.90	4.02
Thruput (Mb/s)	3.57	3.29	3.29	3.56
EC (J/pkt)	0.29	0.17	0.17	0.29

Table 20. Simulation results (10 streams).

Metric	sim #1	sim #2	sim #3	sim#4
PDR (%)	65.70	82.30	82.40	65.80
Delay (ms)	3.58	9.81	9.85	3.61
Jitter (ms)	4.37	14.30	14.40	4.45
Thruput (Mb/s)	3.55	3.25	3.25	3.54
EC (J/pkt)	0.26	0.19	0.19	0.26

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

$$AIR_i = c_i \times PIR_i , \quad (8)$$

where AIR_i denotes the aggregated improvement ratio for the $i^{\prime th}$ metric and c_i represents the weight for $i^{\prime th}$ metric. *AIR* reflects the impact of performance improvement or deterioration of a metric on the overall metrics' satisfaction. *AIR*s 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. The *SIRI* values of the simulations in Fig.3 are computed and listed in Fig.4 –Fig.6.

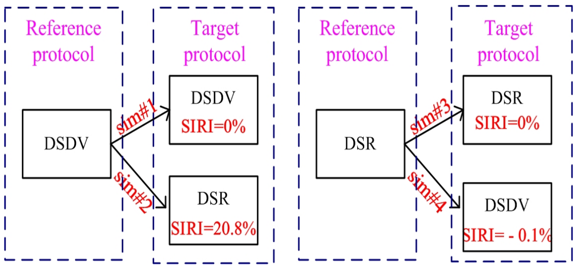

Fig. 4. SIRI results (2 streams).

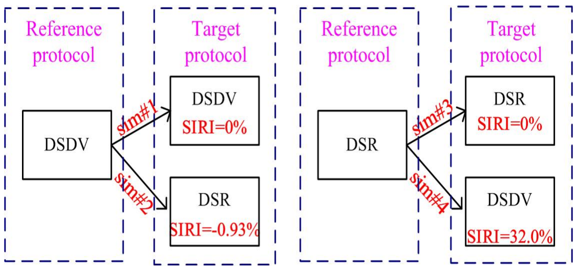

Fig. 5. SIRI results (6 streams).

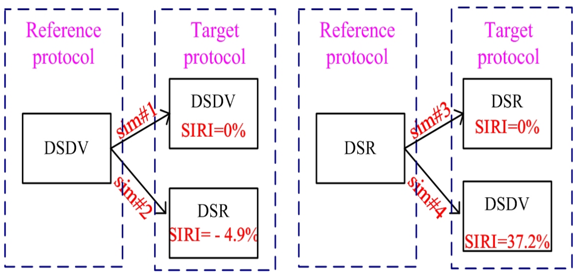

Fig. 6. SIRI results (10 streams).

As shown in Fig.4, an improvement ratio of 20.8 % is obtained in Sim#2 via switching from the original DSDV protocol to DSR. On the contrary, when DSDV replaces the original DSR as that in sim#4, the overall performance deteriorates. It is therefore concluded that DSR is more suitable for the case of 2 traffic streams, which is identical with results in Table 17.

Nevertheless, a negative *SIRI* in Fig.5, though it is marginal, is observed, demonstrating the performance deterioration, when DSDV is replaced by DSR in Sim#2. In contrast, a significant improvement level can be achieved by choosing DSDV as shown in Sim#4. In conclusion, DSDV is better in case of 6 streams. Similarly, DSDV is more preferred in terms of 10 streams as shown in Fig.6. As shown, these conclusions are identical with results in Table 17.

5. Conclusion and Future Work

In spite of various attributes and units for different performance metrics, the proposed AHP-SAW model is able to evaluate two routing protocols DSDV and DSR with five competing metrics and thus rank them reliably. Extensive simulations show that appropriate protocol switch, basing on the performance evaluation results, may lead to a 37.2 % improvement at most. Despite only one case being studied in this paper using the AHP-SAW method, it is generic to other cases with different requirements.

The AHP-SAW 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 AHP-SAW model will be fuzzified to incorporate the standard deviation of simulation results as well as the uncertainty of the decision maker.

Acknowledgment

The project was supported by the State Key Laboratory of Advanced Optical Communication Systems Networks and Suzhou Science and Technology Fund (SZS201304).

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