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A NOVEL LOAD BALANCING ALGORITHM FOR ON-BOARD HIGH-SPEED TRAINS

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Abstract. *It is getting more and more attention to provide high quality Internet service for users in high-speed trains. However, most current Internet access schemes can only serve users via one wireless access technique which obviously restricts transmission quality provided to users. Therefore, this paper provides a novel resource scheduling method called as Throughput-Optimize Load Balancing Algorithm (TOBA). Through evaluating the link metrics, this algorithm can schedule the data flows by round-trip-delay and package loss rate. Compared with related works, our proposed algorithm has better performance for users in high-speed trains in the aspect of bandwidth, transmission delay and link utilization efficiency.*
Keywords: High-speed, Mobile router, Scheduling, Round-trip time, Packet loss rate

1. **Introduction.** With rapid development of High-Speed Train (HST) and mobile Internet all over the world, the high-speed mobile Internet becomes more and more popular; especially in China, the number of passengers for each year has reached to about 2.1 billion according to the Railway Statistical Bulletin published by national railway station in April 2014 [1].

Meanwhile, as showed in the 35th China Internet Network Development Statistics Report, the number of Internet users who would like to access Internet via mobile phones has grown up to about 0.557 billion [2]. So it is becoming more and more crucial to provide reliable and stable wireless communication system with high quality for passengers on HST who need to be served by real-time infotainment and business applications via various mobile terminals.

Recently, North America, Europe, Japan and China have all begun to do research on the wireless techniques for HST environment, such as mentioned in [3], passengers in the Thalys high-speed train has enjoyed broadband Internet access and some other companies have also provided Internet service by bidirectional satellite technology.

However, the wireless techniques showed in [4-6], such as Wi-Fi, Ratio over fiber, 802.11, used in HST still have various disadvantages, summarized as follows.

1) Each wireless access technique has its own fixed features. For example, although accessing Internet via satellite can reduce the handover times, the oversized round-robin time will pull down Quality of Service (QoS) of wireless link.
2) These different wireless access techniques cannot ensure smooth wireless communication when train is moving over 300KM/h.

Therefore, it is necessary to coordinate various existing technologies to achieve reliable and stable wireless communication in HST. The related literature can be classified into two kinds of scheduling algorithms, Round Robin scheduling (RR) and Weight Round Robin scheduling (WRR). RR is a simple and fairness algorithm which only fits for the scenario where the performances of all links are similar, while WRR can improve utilization by distributing flow to links according to definite weight which is evaluated and calculated by the performance parameters of all the links including packet loss ratio, signal intensity, signal to noise ratio, round trip time. Therefore, the problem of load balance can be transformed into multi-element assessment problem. Standard Deviation (SD) is a representative method to calculate multi-element weight, which calculates the element weight to make the data deviation minimum. However, SD cannot be used directly in high-speed mobile system due to highly dynamic transmission links. In this paper, a novel load balancing algorithm is proposed to be more effective and simple especially for On-board High-Speed Trains than SD and RR.

This paper is organized as follows. Section 2 models the HST system. Section 3 provides theoretical principle. Section 4 analyzes performances of the proposed algorithm based on MATLAB. Finally, Section 5 concludes the paper.

2. **System Model.** Referred to [7], a new routing system applied to the HST is shown in Figure 1. The Mobile Multilink Access Router (MMAR), a network entity located on train, acts as the server to provide Internet access for passengers. And the transmission between passengers and application server is supported by the MMAR.

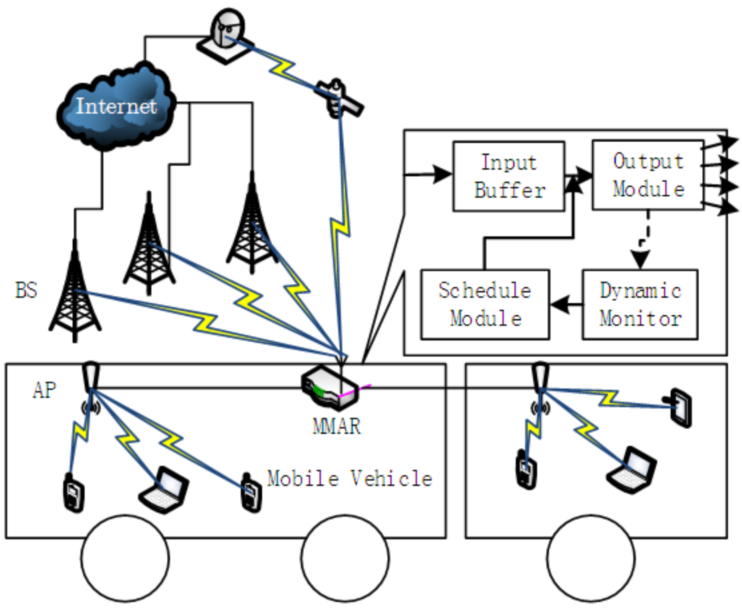

FIGURE 1. Wireless network model in HST environment

MMAR consists of 4 modules, i.e., Input Buffer (IB), Dynamic Monitor (DM), Output Module (OM), and Scheduling Module (SM).

The function of DM is to gain and announce dynamic parameters which include received signal strength indicator, Round-Trip-Time (RTT), packet loss rate, and so on. After receiving dynamic parameters of each link from DM, SM can judge the links' availability and calculate transmission ratio of available links. Then, OM will send data according to the result from DM, which can make MMAR collaborate wireless resource smartly.

3. **Throughput-Aware Load Balancing Algorithm.** The load balance is a key technology to take fully use of network resource. In order to increase the bandwidth and utilization efficiency of systems, one kind of suitable load balancing algorithm should be proposed to make users enjoy better network service.

Just like [8], Round-Trip Time (RTT) and packet loss rate, instead of the non-quantitative parameter, can be used to evaluate the performance of wireless channels quantitatively. According to current congestion control mechanisms [9-13], there are 4 different mechanisms in data transmission, including slow start, congestion avoidance, fast retransmit and recovery. Firstly, to calculate transmission time of the data flow, we assume that,

1) The transmitter sends data at the maximum rate. That is, the transmission window equals congestion window (CWND); and the receiver will respond with an Acknowledgement (ACK) packet after receiving s packets, which is similar to the delayed response mentioned in RFC 2581;

2) The transmission delay of data flow, calculated from packets dispatching by the transmitter to one or more ACK receiving by transmitter, is far more than queuing delay and the processing delay, which means the endpoint buffer is discarded;

3) The transmission delay is related to performance, rather than transmission window.

Based on the above assumptions, the loss of packets in every transmission windows is random and meets independent and identical distribution.

According to congestion control mechanism, each loss of packet will cause transmitter timeout or receiving at least 3 repeat ACKs, which are the sign of the fast retransmission and the recovery respectively. And if there is no packet loss, the flow transmission will be in the slow start and congestion avoidance.

Therefore, the total transmission time of data flow can be calculated as follows,

$$T = \sum_{1}^{K_1} T_{1,i} + \sum_{1}^{K_2} T_{2,i} + \sum_{1}^{K_3} T_{3,i} \tag{1}$$

where K_1 is the total number of slow start and congestion avoidance, K_2 and K_3 are the number of fast retransmission and fast recovery respectively; and $T_{1,i}$ $(1 \leq i \leq K_1)$ is the transmission time of the i^{th} slow start and congestion avoidance; while $T_{2,i}$ $(1 \leq i \leq K_2)$ and $T_{3,i}$ $(1 \leq i \leq K_3)$ are the time of fast retransmission and recovery respectively.

Obviously, if we assume that a wireless link with packet loss rate p and round trip time RTT, in order to transfer N packets successfully, there should be average $N/1-p$ packets to send to the receivers where $Np/1-p$ packets will be lost.

If N_i packets are transmitted without loss and the receiver sends one ACK packet after receiving s packets, the transmission time is,

$$T_{1,i} = \begin{cases} \left[\log_h\left(\dfrac{N_i\cdot(h-1)}{W_{\mathrm{B},i}}+1\right)\right] r, & N_i \leq N_{\max,i} \\ \left[\log_h\left(\dfrac{W_{\max,i}}{W_{\mathrm{B},i}}\right)+1+\left(W_{\mathrm{E},i}-W_{\max,i}\right)s\right] r, & N_i > N_{\max,i} \end{cases} \tag{2}$$

where $W_{\mathrm{B},i}$ and $W_{\mathrm{E},i}$ are the initial CWND and the window at the end of congestion avoidance respectively; and $W_{\max,i}$ is the maximum transmission window at the end of slow start; r is the current round trip time of the wireless link; h can be calculated by $1+\frac{1}{s}$, where s is the number of packets that the receiver must receive from sender to return an ACK packet; and $N_{\max,i}$ is the amount of packet at the end of slow start.

If only the fast recovery can function efficiently in the i^{th} transmission window, the transfer time is $T_{2,i} = (W_{\mathrm{E},i} - W_{\mathrm{B},i})\,sr$. If the waiting time of the first overtime is T_0, then, the relay time of the i^{th} overtime is $T_{3,i} = 2^{i-1}T_0$.

Because of fast moving of trains, the calculation and evaluation processing must be effective as much as possible. On the basis of RTT and packet loss ratio of each link, the average transfer time needed to transmit a data flow with N packets via the wireless link, whose RTT is t and packet loss rate is p, is shown as the following,

$$\begin{aligned} \mathrm{E}[T(N,p,r)] &= T_0\cdot\left(2^{\mathrm{E}(k)}-1\right)+\mathrm{E}(k)sr\frac{W_{\mathrm{E}}}{2} \\ &\quad + r\left(\frac{Np}{1-p}-\mathrm{E}(k)\right)\left[\log_h\frac{W_{\max}}{W_0}+1+s\left(W_{\mathrm{E}}-W_{\max}\right)\right] \end{aligned} \tag{3}$$

where $T_0 = 2r$, $\mathrm{E}(k) = \frac{Np}{1-p} \cdot d_2(p, W_\mathrm{E})$, $W_\mathrm{E} = \sqrt{\frac{8}{3s \cdot p}}$, $W_{\max} = h + \sqrt{h^2 + \frac{2}{3p \cdot s} - 2W_0}$.

It is obvious that $\mathrm{E}(T(N,p,r)) \propto N$ and $\mathrm{E}(T(N,p,r)) \propto r$. So the formula can be changed into the following simplified form when $s = 2$ and $W_0 = 1$,

$$\mathrm{E}(T(N,p,r)) = Nrf(p) = Nr\left(k_1 e^{k_2 p} \cdot p^{k_3 e^{k_4 p}} + k_5 e^{k_6 p}\right) \tag{4}$$

If there are several different wireless links used to transfer data flows, which can be regarded as an M/D/m/c queue system to provide service for each arriving data flow, the transmission percent of the i^{th} link is decided by its transmission performance, specifically, it can be calculated by $\frac{1}{t_i f(p_i)}$, where t_i stands for the RTT and p_i stands for packet loss ratio of i^{th} link respectively.

4. **Performance Analysis.** In recent two years, we have done several actual tests and obtained plenty of data, packet loss ratio and RTT of wireless links in HST scenario covering Beijing-Shanghai high-speed train line. Through our data calculation and statistical analysis, packet loss ratio and RTT in high-speed mobile environment meets certain distributions. And the probability density functions can be fitted in $f(p_{\text{loss}}) = 0.0771e^{-\left(\frac{p_{\text{loss}}-48.06}{18.25}\right)^2}$ and $f(t_{\text{RTT}}) = 0.06372e^{-\left(\frac{t_{\text{RTT}}-541.1}{455.7}\right)^2}$ respectively.

Based on the above actually fitted probability functions, we compare the proposed load balancing algorithm, named Throughput-Optimize Load Balancing Algorithm (TOBA), with referenced algorithms RR and SD focusing on transmission time, bandwidth and link utilization in simulated high-speed mobile environment.

The result is showed in Figure 2 that TOBA is better than other load balancing algorithms on the aspect of transmission time, bandwidth and link utilization. Specifically, TOBA can fall by 78.9% over RR algorithm, and 52.4% over SD algorithm on the aspect of average transmission time. And it can increase throughput by 15.5% to 91.4%. Besides, there is a more than 4% increase in link utilization ratio. And what makes the result of TOBA is better than other 2 load balancing algorithms is the relationship between various parameters, such as RTT, package loss rate and throughput of links. The RR algorithm will transmit packets one by one, that is to say, the RR algorithm will ignore the different performances of different links, which decrease the throughput of system. Although SD algorithm considers different performances of each link, the evaluation of transmission performance is not appropriate which is because that, the relationship between parameters and throughput is nonlinear, but SD algorithm calculates the performance by a linear expression.

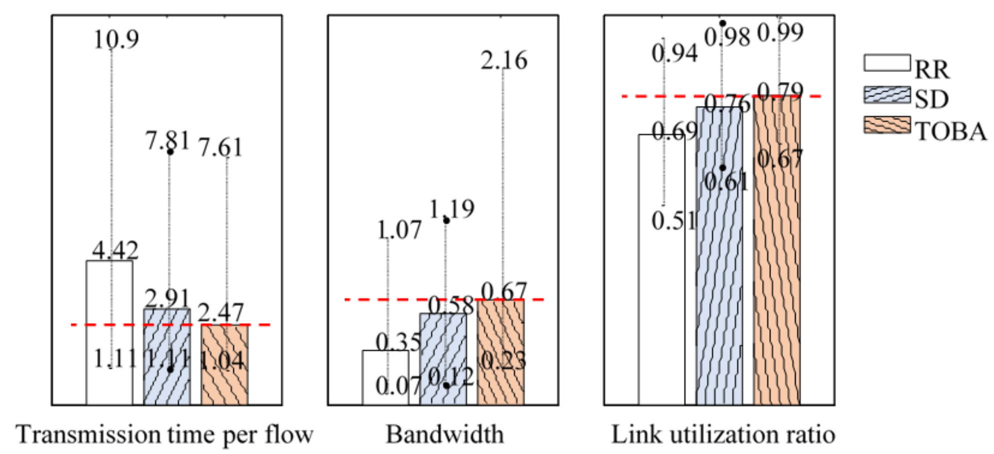

FIGURE 2. Comparisons of different load balancing algorithms

5. **Conclusions.** This paper provides distribution function of packet loss ratio and RTT which is helpful for building actual HST system model on the basis of massive test data. Then, TOBA algorithm is proposed to distribute the data flow fast and efficiently based on transmission performance of all existing wireless links. At last, comparing TOBA with SD and RR on average transmission time, bandwidth and link utilization, TOBA is better than current algorithms in the high-speed simulation environment.

In further research, more tests must be done to verify the performance of TOBA in HST, and according to the test results, improving TOBA algorithm to make system throughput better should be done.

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