Delay Analysis for Train Control Service in LTE-R Railway Communications System

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***Abstract*- The verbal exchange put off of teach manage offerings has a fantastic impact at the song utilization and speed profile of excessive-velocity trains. This paper undertakes stochastic postpone evaluation of teach manage offerings over a high-speed railway fading channel the usage of stochastic community calculus. The mobility version of high-pace railway communications machine is formulated as a semi-Markov technique. Accordingly, the on the spot statistics rate of the wi-fi channel is characterised via a semi-Markov modulated method, which takes under consideration the channel versions because of both big- and small-scale fading outcomes. The stochastic provider curve of high-speed railway communications system is derived based totally at the semi-Markov modulated process. Based at the analytical technique of stochastic community calculus, the stochastic top put off bounds of teach manipulate offerings are derived with each the moment producing function method and the complementary cumulative distribution feature technique. The analytical outcomes of the 2 techniques are compared and tested by simulation.**

1. INTRODUCTION

Over the previous couple of years, multimedia and information-primarily based offerings experienced a non-stopping increase. Unlike earlier than, human beings do now not use the services simplest from a static vicinity, however they are constantly on the move between special scenarios, the usage of their cell devices to get entry to data-primarily based services for paintings-associated functions, amusement or on line socialization. Moreover, humans are not the most effective users of mobile communications, but an increasing number of machines are provided with internet connection and continuously exchange facts.

Commuter traffic from rural areas is also rising, for the reason that maximum work places are in and around cities. The Indian Environment Agency stated in 2013 that traditional commuting instances inside large cities aren't not going to exceed one hour per experience; commuters from rural regions have to endure even longer ride periods. During transportation, human beings intensively employ cell devices to paintings, get entry to to social networks, or as an leisure manner. Internet access is needed for maximum of those services. Whereas now and again the transmission of few bits is sufficient, non-stop streaming of multimedia facts is needed in other cases. However, a full-size part of the cell facts is autonomously created by way of specific varieties of machines. In the sector of transportation, a few examples are the communications for tracking of the kingdom of cars, serving connected leisure structures, or the automated alternate of records between cars. Safety-related applications deserve special attention on the grounds that they impose stringent requirements on factors inclusive of reliability and low latency.

Trains are an efficient manner of transportation for many programs. Although the concept of shifting carriages along rails turned into already discovered in historical civilizations which include the Romans and the Greeks, railway transportation substantially developed over the last few centuries. Its basis is the guided movement of metallic wheels in direct touch with metal rails, which significantly reduces the rolling resistance. Taking also under consideration the capability of joining numerous delivery units, trains are properly acceptable to transport several tons of freight or hundreds of passengers in a totally efficient manner in terms of electricity intake [AM84;

UIC93] in addition to environmental fee [UIC93; Pro95]. However, when airplanes and personal vehicles observed their public within the society, trains had to modernize themselves to be able to be aggressive, particularly concerning pace, discount of cost, and better employer and offerings supplied [Pro95]. Hence, high velocity trains, performing speeds better than 500 km/h, seemed.

This evolution of course additionally affected to railway communications. While the primary communique gadget aimed to help optical signaling become the telegraph inside the XIX century [GFR98; AH11], primitive telephone strains [GFR98] appeared at the beginning of the XX century. Even wireless conversation systems arose for non-crucial communications, along with logistic management or protection tasks. It turned into years later, around the give up of the 70s, when a wireless permanent communications channel among the educate driver and a ground operator become established, which become the predecessor of the so-called GSM for Railways (GSM-R).

2.TRAIN COMMUNICATION TECHNOLOGIES

Train technologies ought to be additionally stated which, although being based on guided cars, keep away from contact of the moving car with the relaxation of the railway infrastructure. There are primary technologies [Pro95]:

Aerotrain: The propulsion is accomplished via a compressed air cushion blown among the vehicle and the bearing substructure [Pro85]. Speeds as excessive as 422 km/h were performed in 1969 in France. Finally, no aerotrain lines had been deployed because the production price in addition to the energy intake in the course of aerotrain operation had been very excessive. Furthermore, the aerotrain ability became lots decrease than for conventional trains.

Maglev: In this example, propulsion is ensured with the aid of magnetic phenomena. Forces required for levitation, propulsion and steering are generated by way of well set-up magnets and coils. The velocity of 517 km/h was done in 1979 in Japan.

Finally, it should be noted that beneath the concept of railways not only the long distance trains are protected, however additionally suburban trains, subways and even trams.

3. PROPOSED METHODOLOGY

The LTE-R system wishes to provide stringent QoS guarantee for those undertaking-vital services. To this stop, assigning devoted radio assets to the first class of offerings is desired to sharing radio sources with the alternative two classes of offerings, despite the fact that better useful resource efficiency may be performed by means of the latter alternative because of statistical multiplexing advantage. So, an thrilling question is what number of resources ought to be committed to those venture-critical offerings to guarantee their QoS performance or what's the anticipated QoS overall performance given a certain amount of committed assets for educate manipulate services transmission? In order to reply this question, we want to assess and quantify the QoS overall performance so that useful insights may be furnished for LTE-R community dimensioning and design. Although the problem of go-layer performance modeling and evaluation of cellular networks and wireless ad-hoc networks has been addressed in literature [5], [6], the overall performance assessment of LTE-R gadget is an open trouble due to the subsequent special functions and requirements in comparison to the LTE public communications machine:

1) Traffic version: The characteristics of teach manipulate offerings are one of a kind from the consumer offerings in public communications machine, which must be studied and modeled for overall performance assessment.

2) Wireless channel: The wireless channel traits for LTE-R system are particular because of the excessive mobility of the trains. The route loss varies swiftly because the teach movements since it in particular relies upon on the gap between the train and the base station (known as evolvedNodeB (eNodeB) in LTE machine). On the opposite hand, the time-correlation of the fading channel turns into very small with the growing mobility speed. These outcomes collectively determine the instant channel profits of the wi-fi channel.

Three) Adaptive Modulation and Coding (AMC): Due to the high mobility of the trains and the brought about fast channel variations, it's miles very tough to acquire accurate on the spot Channel State Information (CSI) on the eNodeBs thinking about the

channel measurements inaccuracy and CSI remarks postpone.

3.1 SYSTEM MODEL

LTE-R Architecture for Train Control System Train control is an essential part of the railway operating control system. Traditionally it connects the constant signaling infrastructure with the trains. In present day train manipulate systems, trains and manipulate centers are connected by mobile communications hyperlinks. Examples are European Train Control System (ETCS)/Chinese Train Control System (CTCS), which might be used for essential line railways in Europe/China; and Communications-Based Train Control (CBTC), that could specifically be used for urban railway traces. The modern-day radio communication networks for ETCS/CTCS are based on GSM-R, that's expected to be upgraded to LTE-R within the destiny.

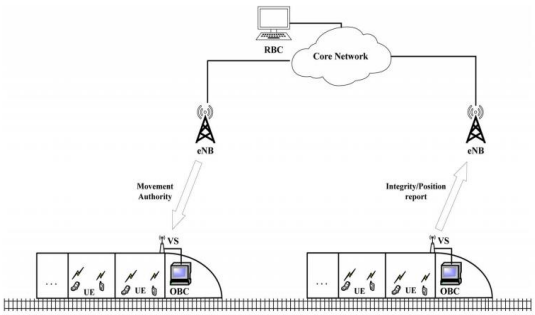

Fig. 3.1. LTE-R communications architecture for train control service.

Fig. 3.1 depicts a simplified view of the LTE-R communication architecture. LTE-R eNodeBs are deployed along the railway line to provide a seamless coverage over the region.

Although the LTE-R specs have not been standardized yet, it's far predicted to be by and large primarily based on the existing LTE specs with some diversifications for the unique characteristics of HSR communications, including the excessive mobility and high priority of educate manage services. In this paper, the LTE-R eNodeBs may be taken into consideration as LTE eNodeBs, except that the proposed AMC scheme as described later is used on the way to adapt to the HSR fading channel. The eNodeBs are related to the middle community through wireline links, while the center community offers connectivity to the train manage centers. To overcome the penetration lack of teach carriages, a vehicle station (VS) is fixed within the ceiling on top of the train. The data site visitors dedicated to educate control entails both downlink and uplink wi-fi transmissions among the VS and eNodeB. In current teach manipulate systems, the educate movement is managed by replacing messages with the manage center, which is known as radio block middle (RBC) in the ETCS system. Each train features a educate integrity control machine and a computer (e.G., onboard controller (OBC) in ETCS) which could manipulate educate pace. It communicates via VS with eNodeBs, that are linked to the RBCs by using the middle community.

Each train exams periodically its integrity and sends the integrity information collectively with the modern-day position of the train head to the RBC, wherein such records is processed. The ensuing records is despatched to the subsequent teach, telling it both that the whole thing is quality to move on using (by means of sending a brand new movement authority message) or that an emergency braking is vital without delay. The verbal exchange postpone between the VS and eNodeB of the educate manage services has first rate impact on the music utilization and velocity profile of excessive-speed trains. The most tune utilization may be completed if trains are following every different with a minimum distance.

Now we have a look at the minimum distance among trains operated under ETCS. We expect trains (Train1 and Train2) at once comply with every different with a maximum velocity vmax and a distance d on a continuous music with out stops, as shown in Fig. 2. At time t1, Train1 completes its integrity check and sends a educate integrity/position record to the RBC. Consider Scenario 1 wherein a part of Train1's carriages is lost right away after t1 from the main educate and prevent where they're. At time $t1 + \Delta\tau$, an up to date teach integrity/role document is sent from Train1 to the RBC which informs the RBC that a part of its carriages is lost, in which $\Delta\tau$ denotes the time between two successive integrity/role reports. After the RBC has processed this file, an emergency braking message is despatched to the subsequent Train2 that is processed there.

As a end result, Train2 starts offevolved to perform braking at a time no later than $t2 = t1 + \Delta\tau + tdelay$, wherein tdelay is the sum of the worst case values of the communication postpone tul of the integrity/role

report to the RBC, the processing time tpr on the RBC, the conversation delay tdl of the emergency braking message to the Train2, and the processing time tpt at Train2. The distance between the head of Train2 to the stopped part of Train1 is d − ltrain − vmax(Δτ + tdelay) at time t2, in which ltrain is the educate length. Assume that the braking distance is lbrake. Then the minimal head-to-head distance d among the 2 trains should be d = ltrain + vmax(Δτ + tdelay) + lbrake to ensure educate safety

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4.SIMULATION RESULTS

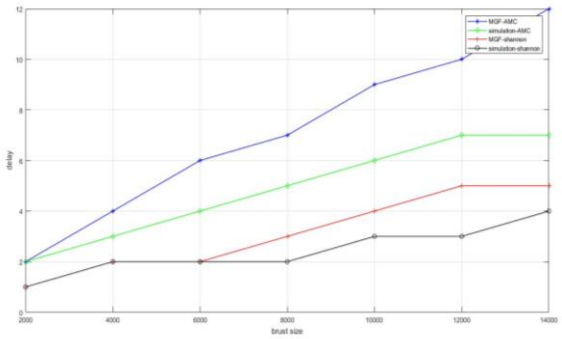

Fig. 4.1 Comparison of simulation results and analytical bounds for periodical source under different burst sizes with AMC method and Shannon method

Fig. 4.1 compares the analytical bounds by means of MGF snetal and the simulation outcomes below extraordinary burst sizes with AMC method and Shannon method, wherein the length of the periodical source is set to τ = a hundred and twenty time gadgets (6 s) and the violation chance is about to 1e − 7, respectively. Fig. 4.1 shows that the postpone bound will increase with the growing burst length, and the growing charge of Shannon approach is slower than that of the AMC technique. This is due to the fact that the duration of burst arrival is τ = one hundred twenty time gadgets and the largest put off experienced by means of the statistics in the buffer (when the burst length is 14000 bits with AMC technique) is bigger than 7 time gadgets with chance no larger than 1e − 7. Therefore, we will adequately conclude that a burst is fully transmitted earlier than the next one arrives, this means that that the biggest backlog equals the burst length and therefore the postpone bound depends on the burst size and the instant statistics price at each zone.

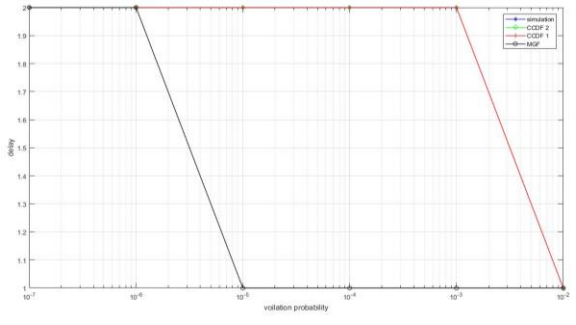

Fig. 4.2 Comparison of simulation results and analytical bounds under different violation probabilities with Shannon method

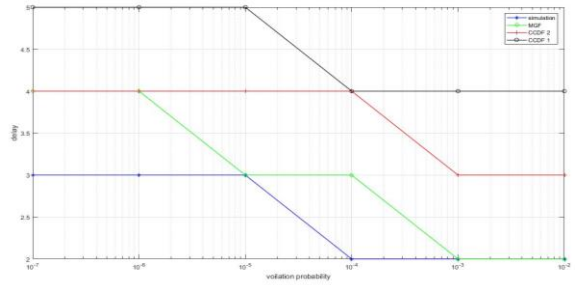

Fig. 4.3 Comparison of simulation results and analytical bounds under different violation probabilities with AMC method

Figs. Four.2 and 4.Three examine the analytical bounds by means of MGF and CCDF snetals and the simulation results under exclusive violation chances, in which the burst size and length of the periodical supply are set to σ = 4000 bits and τ = one hundred twenty time units (6 s), respectively. Fig. 4.2 makes use of the proposed AMC technique to acquire instantaneous statistics charge, even as Fig. Four.3 makes use of the Shannon approach. As expected, the expected delay sure with Shannon approach is smaller than that with the AMC approach, this means that that the Shannon method will offer outcomes which might be extra optimistic than that can be in reality completed. It can be determined that in each figures, the analytical bounds supplied via the MGF method are the tightest at the same time as the ones supplied with the aid of the CCDF method 1 are the loosest. This is due to the fact the MGF technique handiest uses the Boole's inequality and Chernoff sure while deriving the analytical sure via (46), while each CCDF methods use the above inequalities two times (while acquiring the stochastic arrival curves for periodical supply and impairment method by means of (51)). Moreover, CCDF approach 2

provides tighter bound than CCDF approach 1 in Fig. Four.1 and the identical bound with CCDF approach 1 in Fig. Four.2, due to the fact the second bound in Lemma 2 is usually better than the primary sure. Note that the MGF snetal is less difficult to implement than the CCDF snetal, due to the fact that inside the MGF snetal, most effective one free parameter θ desires to be optimized so one can derive the performance sure as in (14). In the CCDF snetal, however, two free parameters θ and θ1 want to be optimized as in (43) and (44).

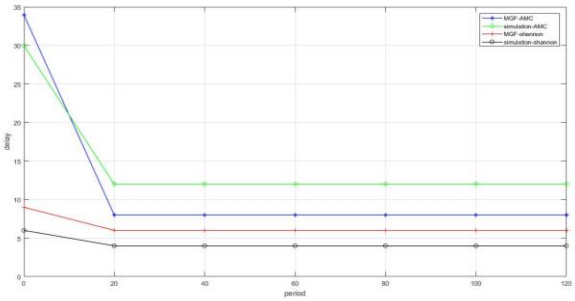

Fig. 4.4 Comparison of simulation results and analytical bounds under different periods with AMC method and Shannon method

Fig. Four.4 compares the analytical bounds by using MGF snetal and the simulation outcomes under one-of-a-kind durations with AMC technique and Shannon technique, where the burst length is about to $\tau = 14000$ bits and the violation probability is about to $1e - 7$, respectively. It can be observed that the delay bound stays to be the equal while the period reduces from one hundred twenty time devices to ten time gadgets for each the AMC approach and Shannon method. However, while the period reduces from 10 time devices to 4 time units, the postpone bound grows quick for the AMC technique (from 7 to forty four time units inside the simulation effects) and grows a bit for the Shannon approach (from 4 to 5 time devices in the simulation consequences).

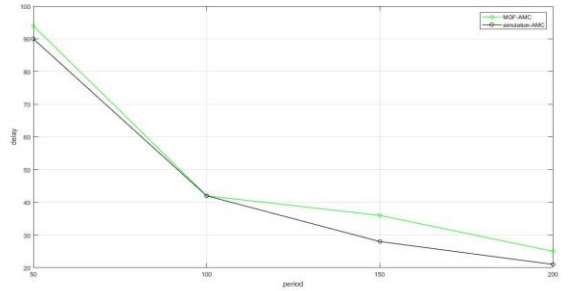

Fig. 4.5 Impact of train speed on delay bound

We set the speed of trains to be a hundred m/s. Note that the train velocity can also affect the postpone bound, for the reason that channel version because of changing path loss will be quicker with better educate speed. In order to observe its impact on the postpone bound, we range the teach velocity from 50 m/s to 200 m/s in a step of 50 m/s. Moreover, so that it will facilitate contrast, we set the area length dz correspondingly in order that the length of a time unit tz stays to be 50 ms irrespective of the educate velocity. Fig. 4.5 shows the analytical sure and simulation outcomes under exceptional educate speeds with AMC technique while the burst length $\sigma = 14000$ bits, length $\tau =$ four time gadgets and violation possibility $\varepsilon = 1e - 7$.

5.CONCLUSION

In this paper, stochastic put off bounds of the teach control offerings over HSR fading channel were derived based totally at the analytical principle behind stochastic community calculus. In particular, the service process of the HSR fading channel became modeled as a semi-Markov modulated system, where the channel versions because of both the massive-scale fading and smallscale fading outcomes have been taken into account. Moreover, the performance loss due to AMC choice with imperfect CSI became also considered. The stochastic provider curve of the semiMarkov modulated provider manner turned into derived the usage of each the MGF and CCDF methods. The educate manipulate service became modeled as a periodical supply, where the stochastic arrival curve can be derived the use of both the MGF and CCDF methods. Based on the stochastic arrival and service curves, the stochastic delay bounds had been derived the use of both the MGF and CCDF methods. It has been proven that for our precise arrival and carrier procedures, the MGF approach can offer tighter sure than the CCDF method and is also simpler to use than the CCDF technique, since it most effective needs to optimize one free parameter. Moreover, we've got also shown that the postpone certain derived whilst thinking about AMC method is indeed more conservative than that derived while the use of the Shannon formulation to derive the immediate facts charge. The numerical and simulation consequences demonstrate that the LTE gadget can

provide excellent delay bounds for teach manipulate services the use of only one aid block. Our attention on this paper is at the performance of educate manage offerings which might be transmitted over committed radio resources. The extension of our evaluation technique to aid all 3 types of offerings consisting of train monitoring offerings and passenger services with a concern queuing system is presently under investigation.

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