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***Abstract*—With the explosive growth of Internet based applications and services, people are relying on Internet in their daily life. This drives a significant demand for provisioning broadband Internet services in high speed trains. In this article, we propose a novel solution named RADIATE (RADio-over-fIber as AnTenna Extender) for high speed train communications. RADIATE utilizes cellular networks as backhauls to avoid the expensive capital expenditure in provisioning broadband Internet services in high speed trains. RADIATE, by applying radio-over-fiber, deploys on-roof antennas and optimally operates these antennas to address the drawbacks of utilizing cellar networks as backhauls. Thus, RADIATE provides a cost effective and high quality communications solution for provisioning broadband Internet services in high speed trains.**

***Index Terms*—Radio over fiber, high speed train communications, antenna systems, cellular networks**

I. Introduction

The market of high speed trains is promising especially in China, Europe, and Japan. With the generous economic stimulus program of more than 586 billion dollars in 2008, China started to accelerate dramatically its railway development and construction. China plans to invest a total of more than 500 billion dollars in order to complete its national rail network of over 120000 km by the end of 2015 [1]. China's State Council plans to triple the length of its high-speed rail network to 40000 kilometers by 2015 from 13000 kilometers in 2011. The plan aims to connect virtually every city with more than a half-million residents by high speed rails.

Provisioning broadband Internet services in high speed trains is important for passengers. According to a survey of 1600 train commuters, 78% of business travelers are interested in using Wi-Fi in trains and 72% would prefer to use trains instead of planes if Wi-Fi services are available [2]. To enable high quality broadband Internet services in high speed trains, many solutions have been proposed. Based on the available access network technologies, these solutions can be classified into four categories: cellular network based solutions, radio-over-fiber (RoF) based solutions, the leaky coaxial cable based network access, and satellite communication based solutions. In this article, we briefly overview these solutions and discuss the drawbacks and technical difficulties involved in these solutions.

Aiming to provide a cost effective and high quality communication solution for high speed trains, we propose a novel RoF based communication solution named RADIATE (RADio-over-fIber as AnTenna Extender). This solution utilizes cellular networks as backhauls for Internet access in high speed trains. Owing to the seamless deployment of cellular networks, relying on cellular networks as backhauls avoids the capital expenditures on deploying network infrastructures dedicated for high speed train communications along the rails. Besides, cellular networks undergo significant improvements and are expected to deliver an ultra high data rate. The difficulties encountered by cellular network based solutions are rapid channel variations and overly frequent handovers. In order to address these difficulties, we propose RADIATE which is a RoF based communication system deployed in high speed trains. RADIATE consists of three parts: the on-roof antenna system, the RADIATE control system, and the in-cabin wireless access points. The RADIATE control system optimally operates the on-roof antenna system to maintain a relatively stationary channel between high speed trains and their serving base stations (BSs). In addition, by coordinating traffic from different wireless access points, the RADIATE control system optimizes the handover processes to mask the handover delay from the passengers and alleviate the quality of service (QoS) deterioration caused by the handover processes. However, realizing RADIATE is not trivial. Thus, we discuss the design issues and research challenges involved in designing and optimizing RADIATE.

II. Existing Solutions: State of the Art

In this section, we provide a brief overview of existing solutions for providing broadband internet access to high speed trains [3]. We classify these solutions into four categories based on network access technologies.

A. Cellular Network based Solutions

Since cellular networks are almost seamlessly deployed and able to provide internet accesses to mobile users, the cellular network based solution is a good choice for provisioning broadband internet services to mobile users. Currently, the dominant wireless communication system for railway is the global system for mobile for rail (GSM-R) [4]. The GSM-R network is based on the second generation mobile communication techniques which can only provide a data rate of upto $200kps$ to mobile users. In order to provisioning broadband internet services, the Long Term Evolution (LTE) has been chosen as the next generation railway communications system by International Union of Railways (UIC) [5]. The LTE system, which enhances the spectrum and power efficiency, provides higher data rates to mobile users. However, the LTE system is not optimized for fast moving users, e.g., users moving at a speed of $300-500km/h$. Providing broadband internet access to high speed trains through LTE networks encounters two major technical difficulties: the drastically changing channel condition and overly frequent handovers [6].

LTE adopts Orthogonal Frequency Division Multiplexing (OFDM) as its transmission scheme. This scheme is robust to frequency selective fading because the bandwidth of the subcarriers is much smaller than the coherent bandwidth of the channel. However, the fast channel condition changes the Doppler spread, which deteriorates the orthogonality among the subcarriers, and lead to severe Inter Channel Interference (ICI). Several approaches have been proposed to mitigate the performance deterioration caused by the Doppler spread. The first approach is to estimate and remove the frequency offset. The second approach is to apply signal processing and frequency domain coding to reduce the sensitivity of the OFDM system to the frequency offset [7]. The third approach utilizes antenna array to compensate for the Doppler spread [8].

Another challenge in delivering broadband internet services to high speed trains through LTE is the overly frequent handovers. On the one hand, since the train is moving very fast, users in the train traverse the overlapping coverage area in a very short time. The handover process may fail and the users will be out of service with a large handover delay. On the other hand, since a cabin of the train may carry tens of passengers, all the passengers will request handover at almost the same time. This may lead to signaling congestion which prevents users from handing over successfully. To address this challenge, Karimi *et al.* [6] proposed a Cell Array solution which organizes LTE cells along a railway and sets up a femto cell in the train cabin to aggregate traffic demands. The Cell Array solution enables a seamless handover by predicting the upcoming LTE cells based on the movement of the train.

B. Radio over Fiber

Radio over fiber (RoF) is a well established technique for distributing wireless communication signals [9]. The distributed antenna system (DAS) is one of the major applications of the RoF technique. In a DAS, multiple remote antenna units (RAUs) are connected to a central unit via RoF transmission links. The RAUs are able to provide excellent coverage and dedicated capacity for short range communications.

By taking advantages of the RoF based DAS, the ”moving cell” concept was proposed to mitigate the handover difficulty for high speed trains [10]. The handover process is in fact the process in which the users negotiate and change their operating frequency to a new BS. The idea of the ”moving cell” concept is that, instead of requiring the passengers to adapting frequency during the handover process, the BSs track the movement of the trains and reconfigure their operating frequency accordingly to maintain the communication links with the passengers. To realize the ”moving cell” concept, the RAUs are deployed along the rails to provide seamless coverage for the train. These RAUs are connected via fiber links with the central unit that tracks the movement of the train and reconfigures the operating frequency of these RAUs. Owing to the low latency of fiber links, the cell reconfiguration is easily synchronized with the movement of the train. In the train, several wireless access points with radio interfaces of multiple access technologies are set up to aggregate traffic from the passengers. These wireless access points relay traffic between users and the RAU along the rail. Based on the ”moving cell” concept, many solutions have been proposed to enhance the performance of the RoF based DAS system [4].

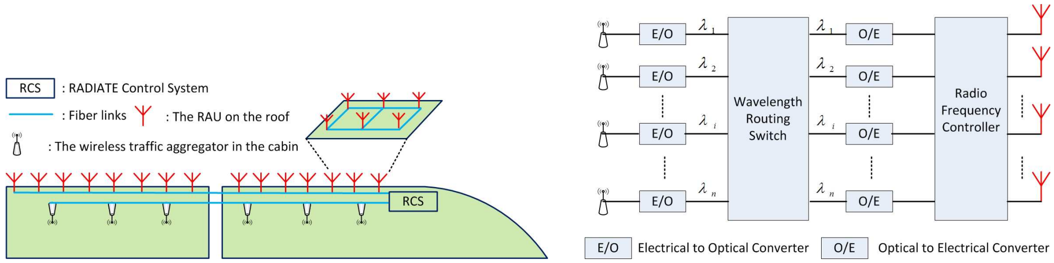
One of the major limitation in implementing the ”moving cell” concept is the huge cost in deploying the fiber connected RAUs along the rails. For example, in China, the railway transportation is the major transportation method for her residents. Thus, the rails are vastly deployed in the territory of China. Deploying RAUs along these rails is extremely costly. In addition, it is even impossible to deploy RoF based DAS in some mountainous terrains.

C. Leaky Coaxial Cable based Network Access

Leaky coaxial cable (LCX) is used as antenna for data transmission and reception. The cable is slotted on its outer conductor to enable the signal transmission and electromagnetic wave radiation [11]. LCX is deployed along the railway lines in Japan for radio communications on the trains. LCX can be utilized as backhaul connections for provisioning Internet services to passengers in the trains. Ishizu *et al.* [11] proposed Mobile-LCX architecture for Internet service on ”Bullet-Train”. In each train, a Mobile Bridge, which consists of radio interfaces for different types of access technologies such as IEEE 802.11, WiMax, and LCX, is deployed to aggregate data traffic in the train and communicate with the LCX based stations. The maximum data rate of the LCX based communication is 768kps which cannot satisfy the bandwidth requirement for broadband Internet services.

D. Satellite Communications

Owing to their vast coverage area, satellites can be utilized to provide Internet services to the passengers in a train [3]. In order to connect with satellites, a pointing system, which performs the satellite acquisition and tracking, is set up in the train. In addition, a communication subsystem is deployed to aggregate data traffic within the train. Providing broadband Internet services via satellite links has several drawbacks [10]. First, the delay of satellite communications, which is about $500-600ms$, is not suitable for real time Internet applications. Second, the bandwidth of satellite links is limited and cannot satisfy the explosive traffic demands from hundreds of passengers in the train. Third, satellite communications highly depend on the weather conditions and the terrain environment. In rainy days, the satellite signals are severely attenuated by the rain, thus resulting in significant capacity decrease. In addition, the satellite coverage in urban areas and hilly areas is very poor, and satellite signals cannot reach tunnels.



(a) The RADIATE architecture.

(b) The RADIATE control system.

Fig. 1. The illustration of the RADIATE architecture and the control system.

III. RADIATE ARCHITECTURE

Provisioning broadband Internet services to high speed trains based on cellular networks is probably the most economic solution because of the nearly seamless coverage of the network. However, the drastically varying channel condition and the overly frequent handovers significantly deteriorate the performance of cellular networks. Meanwhile, the "moving cell" concept based on RoF technologies is promising in providing high quality broadband Internet accesses to passengers in a high speed train. The solutions based on the "moving cell" concept yet require deploying the distributed antenna along the rails, which not only introduces gigantic capital expenditures (CAPEXs) but also incurs the huge operating expenditures (OPEXs) on maintaining the vastly deployed antennas, especially in the rural terrains.

By exploring and marrying the merits of the cellular networks and the "moving cell" concept, we propose a novel broadband communication solution named RADIATE (RADio-over-fIber as AnTenna Extender) for high speed trains. RADIATE utilizes the fiber links to form an antenna system on the roof of the train, which virtually extends the antenna of individual users. As shown in Fig. 1(a), RADIATE consists of the in-cabin wireless access points, the on-roof antenna system, and the RADIATE control system (RCS).

The in-cabin wireless access points have radio interfaces of multiple access technologies such as LTE, WiMax, and WiFi. The passengers in the train access Internet services via these access points. The on-roof antenna system communicates with cellular networks and relay the data traffic between the users and the cellular networks. The purpose of introducing the on-roof antenna system is to camouflage/shield the rapid channel variation and frequent handovers from the users. The RCS has two functions. The first one is to schedule passengers' traffic to maintain fairness among users and fully explore the capacity of the on-roof antenna system. The second one is to optimize and control the antenna system to maximize the network capacity.

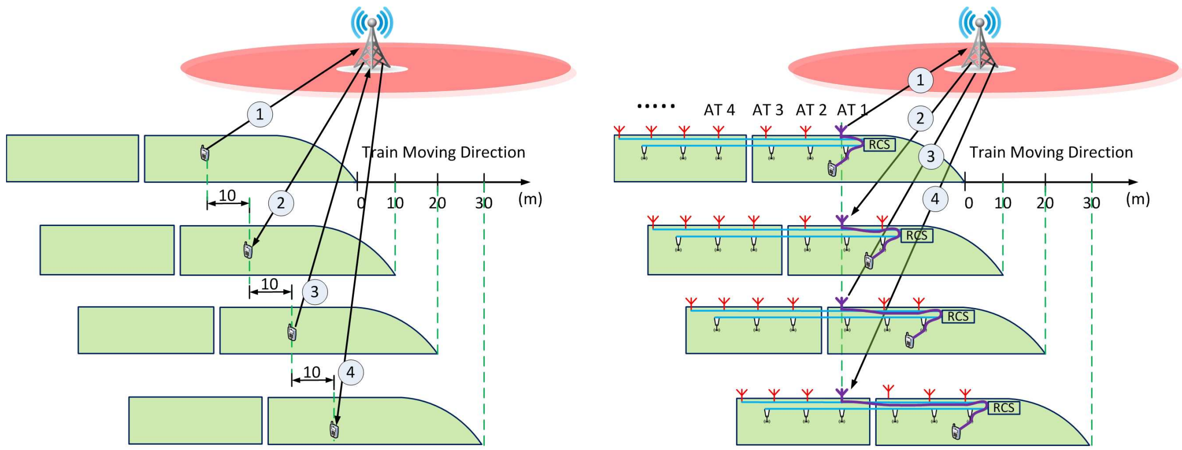
A simple implementation of RCS is shown in Fig. 1(b). The wavelength routing switch is applied to balance the traffic among different antennas. RCS consists of electrical to optical (E/O) and optical to electrical (O/E) converters that may incur delay. Moreover, the signal propagation in optical fiber may also introduce various delays. These delays may impact the capacity of the RADIATE system. To solve this problem, various time-delay modules can be introduced to RCS [4], [12]. Since a train usually has a length of $200-500m$, the antennas at different location on the roof may have different channel conditions. Thus, traffic balancing is required to optimize the utilization of the on-roof antenna system. Radio frequency controller (RFC) is to process the signals received from the antennas or transmitted to the antennas. The design and optimization of the RFC is essential for RIADATE. In order to shield the channel degradation caused by the high speed movement, the antenna system may be grouped into multiple antenna clusters and the signals received by the antennas in a cluster are jointly processed to enhance the signal to noise ratio. In addition, the RFC tracks the speed of the train and the round trip time of connecting the cellular network, and adapts its signal processing processes accordingly. Note that RADIATE does not require any changes in cellular networks and does not assume any specific frame structure and resource allocation strategy adopted in cellular networks.

Since RADIATE relies on cellular networks as the backhaul for delivering broadband Internet services to the high speed trains, we present two illustrative examples to show how RADIATE addresses problems of the rapid channel variation and overly frequent handovers, which are the major issues of cellular network based solutions, in the following two subsections.

A. RADIATE addresses rapid channel variation

The fast moving of the train deteriorates the communication links between the passengers and the serving BSs from two aspects. First, the fast moving introduces the Doppler spread, which leads to severe inter channel interference. Second, the channel quality measurement is deactivated because of the fast moving. In other words, the channel condition when the passengers receive the acknowledgment for the serving BS may change dramatically as compared to the channel condition reported to the BS. In the following, we illustrate how RADIATE enables a relatively stationary channel between the antennas and the serving BSs. When relative stationarity is achieved, the channel condition may not change dramatically. Besides, it is easier for the receivers to apply Doppler shift compensation to reduce the inter channel interference.

The round trip time (RTT) of LTE networks is roughly 70-140ms [13]. The velocity of the high speed train is 300-500km/h [10]. Assume the RTT of LTE networks is 100ms



(a) The original communications scheme.

(b) The RADIATE communications scheme.

Fig. 2. The advantages of RADIATE on addressing the rapid channel variations.

and the velocity of the high speed train is $100m/s$. A user moves $10m$ during a RTT. As shown in Fig. 2(a), if a user communicates with the BS directly, when the user receives the acknowledgement for its first request, the user has already moved $10m$ away from the user's original location. Such a fast movement not only leads to severe Doppler spread but also deactivates the channel quality indication reported by the user. These channel variations deteriorate the communication link between the user and the BS.

RADIATE exploits the on-roof antenna system to mask the channel variation from the users as shown in Fig. 2(b). When a user initiates an access request, the user communicates with the BS via AT 1. When the acknowledgement for the request sends back from the BS, AT 1 is already $10m$ away from its original location. The RCS tracks the movement of the train and the RTT of the network and selects the antenna that has the best performance in receiving the signal transmitted to AT 1. In the ideal case, the antenna selected for receiving the signal is located at the original location of AT 1. In the example shown in the figure, AT 2 is selected. Here, selecting AT 2 is actually processing the signal received by AT 2 as the signal was received by AT 1 in RCS. Since AT 2 is located at AT 1's original location, AT 2 is supposed to experience the same channel condition as that of AT 1 reporting to the BS when AT 1 initiates the request. Thus, from the BS's point of view, it seems that the receiving node does not move at all. From the perspective of the users, the rapid channel condition variations are hidden. Since the antennas are deployed along the roof of the train, by proper antenna selection, the RCS is able to maintain roughly stable wireless communication links between the BS and the train for a considerable long time equaling to tens of RTTs. For example, the length of a high speed train in China is 200-500m depending on the configurations. If the high speed train moves $10m$ in every RTT, the RCS can maintain a roughly stable channel condition for 20-50 RTTs in the ideal case, i.e., 40-100 times more time of extended stable communications with a BS using RADIATE as compared to the conventional system.

B. RADIATE addresses overly frequent handovers

The handover process is another difficulty in provisioning high speed trains with broadband Internet services via cellular networks. The difficulty lies on two aspects. The first one is that owing to the high velocity of the train, it requires a strictly short handover delay. The passengers in the train pass the overlapping area very fast. If the handover delay is not short enough, the passengers will lose their network connections. The other one is the handover congestion. A high speed train usually carries hundreds of passengers who will request handovers at almost the same time. This leads to handover congestion in the BS which may result in an unacceptable handover delay.

By exploiting the on-roof antenna system, RADIATE conceals the handover delay from the passengers and balances the traffic load among the antennas to avoid the handover congestion. In fact, the passengers are connecting with the in-cabin wireless access point and do not execute the handover process directly with BSs. RADIATE manages its on-roof antennas to handover its communication connections among BSs. As shown in Fig. 3, UE 1 initiates network access when the UE is located in the red cell. When the train is moving into the green cell, instead of handovering UE 1 to the green cell immediately, the RCS selects the antennas which are still in the red cell, e.g., AT 5, to serve the UE's traffic demands. After the train has established communication links with the green cell, UE 1's traffic demands can be switched to the green cell. In this way, the passengers in the train will not experience the handover delay.

To avoid handover congestion, RADIATE redistributes the passengers' traffic demand among the antennas. In the example shown in Fig. 3, when UE 2 initiates the network access, the UE is located in the red cell. The RCS predicts that UE 2 will eventually handover to the green cell according to the movement of the train. Thus, the RCS handovers UE 2's traffic load to the green cell in advance. Although UE 2 is still in the red cell, the RCS directs UE 2's traffic to AT 2. As a result, the UE 2's traffic demands are handovered to the green

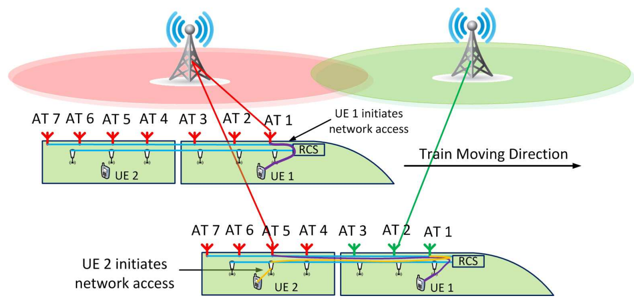


Fig. 3. The RADIATE handover process

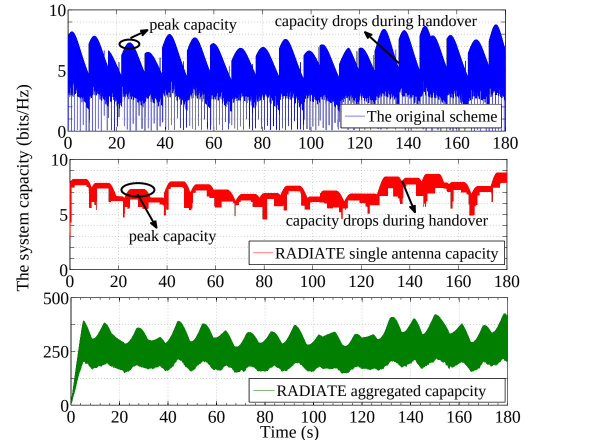


Fig. 4. The system capacity comparison.

cell. When the train is within the coverage of multiple cells, the RCS determines the traffic demands distribution among these cells and selects proper timing for handovering these traffic demands. The RCS can delay the handover of certain users' traffic demands, e.g., UE 1 while bringing forward the handover of other users, e.g., UE 2. The traffic demand distribution and the handover timing are optimized by the RCS to maximize the performance of RADIATE.

C. Capacity Comparison

We compare the downlink system capacity of RADIATE and the original communication scheme in WiMAX networks. In the simulation, the high speed train traverses an area covered by 21 WiMAX BSs at a velocity of 100m/s. The distance between two adjacent BSs is randomly selected from 1 km to 1.5 km. We adopt Ereg's empirically path loss model with terrain category B [14]. The length of the train is 500m and 50 antennas are deployed in a row on the roof of the train. The distance between two antennas is 10m. The system capacity is calculated based on Shannon-Hartley Theorem. The impact of handover process is simply reflected in the signal-to-interference-and-noise-ratio (SINR) in the simulation. Note that this simulation aims to show the advantage of the RADIATE concept rather than evaluating the implementation of the RADIATE system. In Fig. 4, the first sub-figure shows the system capacity of the original communication scheme with single antenna. Owing to its high speed, the train travels through the coverage area very fast and incurs frequent handovers. When the train moves away from a BS, the system capacity drops dramatically. Thus, the system capacity of the original scheme goes up and down. Since the train moves very fast and experiences various channel fading, the system maintains its peak capacity for only a very short time. As compared to the original scheme, RADIATE shows two advantages. First, RADIATE maintains high system capacity for a longer time. As shown in the second sub-figure of Fig. 4, by leveraging its antenna system, RADIATE selects the antenna with the best channel condition as the serving antenna and enables the system to maintain its peak capacity for a longer time. Second, RADIATE reduces the capacity drops during the handover process. Thus, RADIATE is able to ensure quality of service even during handover processes. If all the antennas are utilized simultaneously, the aggregated system capacity is significantly enhanced which is shown in the third sub-figure. Here, we assume that each antenna occupies an orthogonal channel and the aggregated system capacity equals to the summation of the capacity provisioned by a single antenna. The aggregated system capacity may be further enhanced if joint processing among these antennas are enabled.

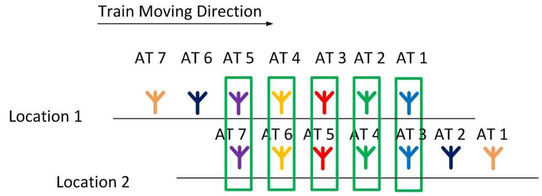
IV. Research Challenges

The major research challenges of realizing RADIATE are designing the on-roof antenna system and the RADIATE control system. In this section, we discuss these research issues and challenges.

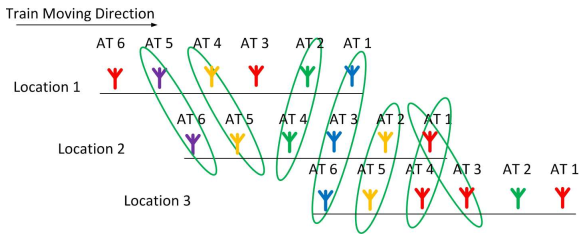
A. On-roof antenna system design

There are two issues in designing the on-roof antenna system. The first one is the antenna deployment. One of the major purposes of deploying the on-roof antenna system is to obtain a relatively stationary channel between a high speed train and its serving BS. If antennas are densely deployed, the probability that RADIATE obtains a relatively stationary channel is high; otherwise, when the antenna is sparsely deployed, the probability is reduced. Fig.5 illustrates the antenna deployment issues. A passenger sends data requests when the train is at location 1 and receives the acknowledgement when the train is at location 2. If antennas are densely deployed as shown in Fig. 5(a), at location 2, RADIATE utilizes AT 3 to receive the acknowledgement for the passenger's data request sent by AT 1 when the train is at location 1. In this case, RADIATE is able to obtain a relatively stationary channel between the BS and the train by adapting the receiving antennas. If the on-roof antenna is sparsely deployed as shown in 5(b), RADIATE may not be able to align the antennas to obtain the relative stationarity.

Densely deploying antennas may also increase the system data rates. These antennas can emulate a multiple input multiple output (MIMO) system to increase data rates via multiple stream beamforming, spatial multiplexing, or diversity coding. In this case, the RCS may optimally group the antennas into different clusters to perform as an MIMO transceiver. In addition, the RCS may adapt the antennas usage pattern, e.g., multiple stream beamforming or spatial multiplexing, based on



(a) The dense antenna deployments.



(b) The sparse antenna deployments.

Fig. 5. Illustration of the antenna deployment.

the channel conditions. To enhance the handover performance, more antennas are expected to be deployed on the head cabin of a train. Because the head cabin of a train enters a new radio cell first, it is desired to provision higher capacity in the head cabin of the train to enable the flexibility of handovering data traffic to the new radio cell.

As compared to a sparse antenna deployment, a dense antenna deployment enhances the network performance at the cost of not only the CAPEX but also the complexity of the RCS. Deploying a large number of antennas may require multiple wave lengths for carrying the aggregated data traffic with fiber links. It increases the cost and the complexity of the RCS. Besides, in order to optimally utilize these antennas, sophisticated algorithms should be implemented in the RCS, which also complicates the design of the RCS. In addition, the network performance may not monotonously increase versus the density of the on-roof antennas. Therefore, the trade off between the network performance and the system cost and complexity should be carefully evaluated.

B. *RADIATE control system design*

The RADIATE control system realizes three major functions: 1) the antenna system control and configuration, 2) the RoF link optimization, and 3) the traffic scheduling.

1) Antenna system control and configuration: The goals of the antenna system control and configuration are to obtain a relatively stationary channel between the train and its serving BSs and to enhance the reliability and capacity of wireless communication links. In order to obtain the relative stationary channel, the RCS estimates the RTT between the on-roof antennas and their serving BSs. Based on the RTT estimation, the RCS calculates the traveling distance of the train within one RTT and selects the antenna closest to the location where the last communication link was established as the receiving antenna for the corresponding acknowledgment. Since the route of a train is predetermined, RTTs can be measured offline and stored in the RCS. The RTT estimations are retrieved based on the location of a train during the operation of the train. Selecting a new serving antenna needs to adapt the antenna's operating frequency. After changing the operating frequency, the antenna is required to synchronize with the serving BS, which may introduce additional cost. In order to reduce such cost, the clock information of the serving BS is stored in the RCSs and updated when the original communication link is established. Instead of synchronizing directly with the BS, the newly selected serving antenna adopts the clock information stored in RCSs. Thus, optimally maintaining and updating the clock information stored in RCSs is critical for the RADIATE system. In addition, the Doppler shift compensation information at different locations can also be calculated offline and stored in the RCS. When processing the received signal, the RCS retrieves the Doppler shift compensation information based on the antenna's location and applies the compensation to the received signal.

Given the antenna deployments, utilizing these antennas to enhance the reliability and capacity of the communication links is challenging. For the downlink transmission (from the serving BS to the train), the RCS may apply multiple antennas to jointly receive the signal to reduce the error rates and enhance the reliability of the communication links. For the uplink transmission (from the train to its serving BS), the RCS may adopt multiple stream beamforming to improve the signal to noise ratio (SNR) of the receiving signals in the BS and to establish a reliable communication link in the uplink direction. In addition, given a high SNR, a high order modulation can be applied to enhance data rates of the communication links. Meanwhile, applying spatial multiplexing, the RCS can utilize the multiple antennas to increase the uplink capacity. The RCS can even group the antennas which are located far away from each other, e.g., the antennas at the head of the train and those at the end of the train, into clusters and formulate coordinated multiple point transmission to improve the reliability and capacity of the communication links. All these operation configurations and antenna clustering strategies highly depend on traffic demands, channel conditions, and the antenna deployments. Hence, it is desirable and challenging to design the RCS by fully exploring the advantages of the RoF based on-roof antennas.

2) RoF link optimization: Optimizing RoF links is not trivial [9]. The selection of carrier frequency is important for RoF links. The cost of the semiconductor lasers increases significantly when the modulation frequency is beyond 3 GHz. Therefore, it is desirable to adopt a low carrier frequency to minimize the CAPEX of deploying RADIATE. Since the carrier frequencies of current cellular networks are below 3 GHz, RADIATE can transmit signal over the fiber using the carrier frequency of cellular networks. However, if a higher frequency is utilized in future cellular networks, RADIATE may translate the carrier frequency of cellular networks to intermediate frequency (IF) to avoid excessive expenses on the semiconductor lasers and to enhance the performance of RoF links [9]. When the on-roof antennas are configured as MIMO transceivers, RADIATE requires the transport of multiple radio channels between the RCS and the on-roof antennas using the same radio carrier frequency. In this case, wavelength division multiplexing is employed to minimize the number of required fiber links and the RCS is responsible for the wavelength scheduling [15].

3) Traffic scheduling: Traffic scheduling algorithms are essential to guarantee the performance of RADIATE. Owing to the length of the train, antennas deployed on the roof of different cabins of the train may experience different path losses. Thus, the on-roof antennas provide communication links at various data rates. In order to enhance the system QoS, the traffic demands among all passengers should be well scheduled to select the optimal serving antennas for individual traffic demands. For example, VoIP applications requires small bandwidth but low latency and error rates. Thus, for VoIP applications, RADIATE may utilize the antenna with high SNR or beamforming techniques to meet the QoS requirement of VoIP applications. In addition, the system capacity of RADIATE should be fairly shared among the passengers. Thus, fair traffic scheduling algorithm is desired in the RCS.

During the handover processes, traffic scheduling algorithms are responsible for switching data traffic to a new radio cell. As shown in Fig. 3, during the handover processes, in order to optimize the system performance, some traffic demands should be handed over in advance into a new radio cell while other traffic demands may be better served by the original radio cell. In this case, traffic scheduling algorithms should optimally associate the traffic demands with different BSs to maximize the system performance.

The RADIATE control system is a complex system that involves many design issues. For practical applications, the trade-off between the system optimality and the implementation and computational complexity should be carefully evaluated. For the antenna control and configuration, offline algorithms may be designed because the routes and speed of the trains are in general fixed. Thus, the antenna configurations obtained using an offline algorithm can be stored in RCSs as a lookup table. The RCSs can select the antenna configurations based on the location and the speed of the train. The RoF link and traffic scheduling should be dynamically optimized according to the traffic load. Suboptimal solutions may be required for practicality.

V. Conclusion

This article introduces a novel communication solution, RADIATE (RADio-over-fIber as AnTenna Extender), for provisioning broadband Internet services in high speed trains. We have briefly overviewed the existing broadband communication solutions for high speed train communications. Leveraging RoF technologies, we have proposed RADIATE and presented its system architecture. We have also illustrated how RADIATE addresses the rapid channel variation problem and the overly handover problem in high speed train communications. Finally, we have presented the research issues and challenges in realizing RADIATE.

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