論文の内容の要旨

A High Speed Mobile Communication System implementing Bicasting Architecture on the IP Layer

（IPレイヤにおけるバイキャスティングアーキテクチャを実装した高速移動通信システム）

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Having a broadband connection on high speed rails is something that business travelers want most. Increasing number of passengers is requesting even higher access speeds. We are proposing the Media Convergence System as an ideal communication system for future high speed mobile entities. The Media Convergence System recognizes plural wireless communication media between the ground network and each train, and then traffic is load-balanced over active media which varies according to circumstances. The Media Convergence System must have a pivot wireless communication media. We are focusing on IEEE 802.11g as a pivot medium of the Media Convergence System, because it is expected to have a high performance in communication with high financial efficiency. In order to realize a high speed mobile communication system based on IEEE 802.11g (referred to as IEEE 802.11g Communication System), this paper designs the IEEE 802.11g Communication System, constructs an experimental IEEE 802.11g Communication System on a commercial high speed rail system, and evaluates performances of the system through trials.

The organization of this paper is as follows. Chapter 1 describes a background of this research and overviews this paper. Chapter 2 discusses ideal high speed communication systems in the future based on surveys of train communication technologies so far. The consideration leads a result where a Media Convergence System will be the desired high speed mobile communication system for the future. Chapter 3 through Chapter 7 is divided into two parts. Part 1 consists of Chapter 3 and Chapter 4, in which they stress a necessity of a pivot wireless communication medium of the Media Convergence System and explains that IEEE 802.11g satisfies all the requirements to be the medium. The IEEE 802.11g Communication System is proposed, designed and constructed on a commercial high speed rail system, and then performances of that system are evaluated in this part. Trial results have proven that the IEEE 802.11g Communication System realizes the maximum application throughput of around 20(*Mbps*). On the other side, the results have also clarified that the IEEE 802.11g Communication System suffers from very frequent Layer 2 Handovers (L2HO) which degrade the communication quality. Part 2 consists of Chapter 5 through Chapter 7. In order to solve problems caused by L2HOs, Part 2 proposes the Bicasting-Multipath Mobile IPv4 and it is verified through trials. Trial results have proven that the Bicasting-Multipath Mobile IPv4 improves the communication quality over L2HOs and also stabilizes communication.

Detailed discussions in each chapter are as follows. Chapter 1 describes a background of this research and overviews this paper. The Internet using TCP/IP is not only for immobile computers in rooms but also for any devices under any situation for anyone who wants to use it. It is not an exception when people are on a high speed train traveling at around 300(*km/h*). Although we have demands for connectivity to the Internet from cabins, a supply of communication bandwidth is not enough for the demands in high speed mobile environments. Chapter 1 explains a necessity of making communication bandwidth broader for high speed mobile systems.

Chapter 2 surveys various train communication systems with their history and discusses present systems. The focus of this paper is communication on high speed rail systems. High speed trains generally travel through various geographical areas such as cities, suburbs, mountains, tunnels and so on. With these geographical conditions taken into account, there seems to be no perfect wireless communication medium which suits best to all places. Communication media which have different characteristics from each other should be deployed in accordance with geographical conditions. Plural communication media may become available in the same place at the same time. A wireless communication system for high speed trains in the future must recognize these plural wireless communication media and traffic must be load-balanced over active media which varies according to circumstances. It is referred to as “Media Convergence System” that all the communication media available at local places are logically bundled up into a single path. This chapter proposes a Media Convergence System which will be desired in future high speed trains.

Chapter 3 discusses a pivot communication media of the Media Convergence System. The pivot wireless communication medium for the Media Convergence System has to satisfy four following requirements.

(1) To have enough communication bandwidth

(2) To be feasible and affordable in the near future

(3) To be easy to procure devices for the system

(4) To be easy to operate

After a careful consideration of these requirements, IEEE 802.11g was employed as a pivot wireless communication medium in the Media Convergence System. This research is aiming at developing a broadband communication system based on IEEE 802.11g under high speed mobile environments.

Chapter 3 also designs the IEEE 802.11g Communication System for each layer. Major design policies for each layer are as follows. For a radio transmission channel on Layer 1, a radio propagation line was established on the train track by a high gain directional antenna. The Fresnel Zone was kept as clear as possible to make the quality of the radio transmission channel higher. As for Layer 2, the IEEE 802.11g Communication System leverages IEEE 802.11g as the name indicates. One of the requirements for the system is to construct a system in which it is affordable with the use of IEEE 802.11g. Our policy does not permit any customizations on IEEE 802.11g. Product dependences were accepted on Layer 2. As for Layer 3, design policies are as follows. The IEEE 802.11g Communication System assumes trains as its mobile stations. Since trains move on their tracks, a migration path for each train can be identified unless the train suddenly leaves its intended route. This peculiar characteristic allowed us to design a network topology which minimizes damages to communications caused by L3HOs.

Chapter 4 verifies that the IEEE 802.11g Communication System performs in accordance with the designing intentions and proves that the system works in real situations. The trials were done on a commercial high speed rail system. The speed of the test train was kept at 270(*km/h*). Experimental results have revealed communication performances on the IEEE 802.11g Communication System as shown in Table. 1. Results showed that the IEEE 802.11g Communication System working in Mode 2 had a TCP bandwidth of 13.7(*Mbps*) even while a mobile node was moving at 270(*km/h*). On the other side, however, Table. 1 also clarified a problem of high communication stall duration rate caused by downtimes over L2HOs and wireless link failures. Here, a ratio of communication stall duration to the whole communication period is referred to as Communication Stall Duration Rate.

Table. 1 Communication Performance on the IEEE Communication System

Examined Contents	Results	
IEEE802.11g Link (Wireless Link Failure)	Failed in 5.2%	
Round Trip Time	Average: 9.95(*ms*), Standard Deviation: 5.79(*ms*)	
UDP	Mode 1	Average: 16.3(*Mbps*) Max: 25(*Mbps*) or higher
	Mode 2	Average: 17.7(*Mbps*) Max: 25(*Mbps*) or higher
TCP	Mode 1	Average: 9.86(*Mbps*) Max: Around 20(*Mbps*)
	Mode 2	Average: 13.7 (*Mbps*) Max: Around 22(*Mbps*)
Communication Stability (Communication Stall Duration Rate)	Mode 1	9.9%
	Mode 2	18.1%

In order to reduce Communication Stall Duration Rate, requirements to improve the IEEE 802.11g Communication System were considered. Our policy does not permit any customizations on the IEEE 802.11g. Instabilities on Layer 1 and Layer 2 must be compensated for by Layer 3. These discussions brought three Requirements to be satisfied as follows.

(1) To enable traffic forwarding while a Layer 2 link is down

(2) To eradicate TCP Time Out caused by L2HOs

(3) To be applicable to all transport protocols

In order to improve the IEEE 802.11g Communication System with satisfying these three Requirements, Chapter 5 proposes "Multiplexing of wireless links between the ground network and each train network" and "Bicasting traffic between the redundant paths." Two wireless links between the ground and a train were redundantly established. Each link was recognized as different IP routes (Paths) by MP-MIPv4. This is a bicasting architecture of traffic over two MIPv4 tunnels. The architecture was named "Bicasting-Multipath Mobile IPv4."

Chapter 5 describes our proposal of the Bicasting-Multipath Mobile IPv4. A MP-MIPv4 network for its platform was also designed and the characteristics were considered with experimental results. The results have shown that IPLB (IP-based Load-Balancing) is the best load-balancing algorithm for the IEEE 802.11g Communication System.

Chapter 6 describes a design and an implementation of a bicasting architecture between paths in the Bicasting-Multipath Mobile IPv4. The bicasting architecture works over redundant paths established by MP-MIPv4. In order to satisfy three Requirements of the IEEE 802.11g Communication System held up in Chapter 4, the Bicasting-Multipath Mobile IPv4 bicasts traffic while either a L2HO or a Wireless Link Failure is taking place. Here, bicasting has to be started before the occurrence of either of them. Even if bicasting is started after a detection of a link being down, target traffic is no longer there and thus TCP has to wait for a RTO expiration. Therefore the Bicasting-Multipath Mobile IPv4 has to predict both a L2HO and a Wireless Link Failure before the start of its process.

The IEEE 802.11g Communication System predicted the events by RSSI (Received Signal Strength Indication) which each TBR received from one of the GBRs. RSSI on both TBRs were observed every 125(*ms*) by SNMP get-requests. For the Front BR which was set up at the front edge of the test train, a L2HO was predicted by an occurrence of a RSSI peak. This method successfully predicted L2HOs on the Front BR with the rate of 88.2%. For the Rear BR which was set up at the rear edge of the test train, on the other side, we introduced a threshold to judge a L2HO. The threshold is referred to as "L2HO threshold." When a RSSI fell under this L2HO threshold, a L2HO was predicted. Accuracy on the Rear BR depends on a configurable L2HO threshold.

Chapter 7 reports experimental results of the Bicasting-Multipath Mobile IPv4. Communication performances on the Bicasting-Multipath Mobile IPv4 are shown in Table. 2. The results have proven that the Bicasting-Multipath Mobile IPv4 is able to reduce Communication Stall Duration Rate to 0.67% and realizes TCP Rate of 16.4(*Mbps*) at the same time. Our proposed method improved the Communication Stall Duration Rate which was a serious problem of the Singlepath Configuration. The Bicasting-Multipath Mobile IPv4 realized both high communication speed and low Communication Stall Duration Rate at the same time. We have successfully configured a practical communication system for high speed rail systems.

Table. 2 Communication Performance on Bicasting-Multipath Mobile IP

L2HO Threshold (*dBm*)	TCP Rate (*Mbps*)	Communication Stall Duration Rate	
		Measured (%)	Estimated (%)
-71	16.4	0.67	1.89