

Noble Bandwidth Requirement Estimation method for Wireless Railway Communication System

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Abstract— Sophisticated bandwidth requirement estimation method for wireless railway communications system is introduced in this paper. To derive optimized frequency requirement calculation method, ITU-R M.1390 and 1768 are analyzed and compared.

After that, we define and segment the services required for the next generation railway communication system. A data on equipments that is installed on the actual fields are allocated to the parameters of the calculation process. Consequently expected frequency requirements of present, 5 years later, 10 years later will be presented.

Keywords— Bandwidth requirement estimation, Wireless railway communication system, Services for train operation

I. INTRODUCTION

In wireless communication system operation, precise frequency resource management is the key issue because of its limited characteristics and high cost. It's important to manage limited frequency resources for communication systems efficiently, but allocating rational bandwidth which is suitable for purpose and expenditure is also significant. Through optimal bandwidth allocation, efficiency and justification of wireless railway communication system is improved.

Internationally, wireless railway communication system is being introduced in earnest. Through introducing wireless railway communication system, increment of entire railway traffic, reduction of accident incidence and maintenance cost can be achieved coincidentally. To introduce the wireless railway communication system ensuring various advantages, allocating dedicated frequency band for railway should be preceded.

In this paper, we treat of dedicated bandwidth estimation method for wireless railway communication system. In section II, we execute comparative analysis on ITU-R M.1390 and ITU-R M.1768, which was reviewed for introducing mobile communication system that is currently installed, IMT-2000 and IMT-advanced. Due to differentiation on service type and statistical properties between general mobile communication case and railway communication case, above mentioned methods are not appropriate for railway case. So, noble

bandwidth requirement estimation method for wireless railway communication system is proposed in section III.

After that, bandwidth estimation using the proposed bandwidth calculation method will be executed in section IV. The estimation result of current, 5 years later, 10 years later are calculated in this section. And the conclusions are mentioned in section V.

II. EXISTING BANDWIDTH ESTIMATION METHOD

There are two general bandwidth estimation process applied to the conventional wireless mobile communication system. ITU-R recommends terrestrial spectrum requirement calculation methodology such as ITU-R M.1390[1] for IMT-2000, and ITU-R M.1768[2] for systems beyond IMT-2000. These will be compared and analysed in this section.

A. ITU-R M.1390

ITU-R M.1390[1] is methodology developed for frequency requirement calculation for IMT-2000 system. It is suitable for the case of data traffic processing using single wireless access technology. The estimation process is classified significantly into four stages as follows; 1) Geographic considerations, 2) Market and traffic considerations, 3) Technical and system considerations, 4) Spectrum result considerations.

In geographic considerations stage, environment types are classified according to the combination of mobility and user density first. And up or down link are selected, and the cell area is calculated after configuring of radius and shape of cell. In market and traffic considerations stage, the service type is selected within six categories; speech, switched data(circuit switching above), simple message, medium multimedia, high multimedia, high interactive multimedia(packet switching above). The number of subscribers per cell is calculated using population density and penetration rate. After examining traffic parameters such as busy hour call attempts, call duration and activity factor statistically, we can get data about traffics per subscriber and traffics per cell. The QoS parameters of circuit and packet switching service are configured respectively in accordance with different erlang formula B or C.

In technical and system considerations stage, the number of service channel which is able to process traffics per cell is determined using QoS parameters and erlang formula. After that, cell traffics originated within one cell could be calculated through determining the service channel bit rate. The system capacity should be decided in this stage by considering spectral efficiency, coding factor, overhead factor and deployment model. In spectrum result considerations stage, frequency requirements of a specific environment and service are determined by proportion of cell traffic and system capacity. The calculation process is repeated from 1) to 3), then finally the sum of frequency requirements for uplink and down link is estimated by considering two factors, weighting factor(α_{es}) and adjustment factor(β). An abbreviation ‘e’ means ‘environments’, and ‘s’ means services. The total amount of frequency requirements is expressed by following equation (1).

$$F = \beta \sum \alpha_{es} F_{es} = \beta \sum \alpha_{es} \frac{T_{es}}{S_{es}} \quad (1)$$

B. ITU-R M.1768

ITU-R M.1768[2] describes frequency requirement estimation methodology for future developments of IMT-2000 and system beyond IMT-2000. The ITU-R M.1380 methodology considers a application for single mobile communication system. By contrast, ITU-R M.1768 methodology considers application of multiple mobile and fixed communication system and more complex cases of multi-network environments. This is more suitable than ITU-R M.1380 for modern multiplex communication environment which is able to consider diverse variables.

To estimate total emerged traffic, service category(SC), service environment(SE), radio environment(RE) should be classified clearly. First, SC is divided into SC1~SC20 according to combination of service type and traffic class. The service type is consists of super high multimedia (30Mbps ~ 1Gbps), high multimedia(<30Mbps), medium multimedia (<2Mbps), low data & multimedia(<144kbps) and very low rate data(<16kbps). And the traffic classes are classified depending on the sensitivity of QoS in the following order; conversational, streaming, interactive, background. The SEs are defied as a similar service utilization region, and classified as SE1~SE6 depending on service usage patterns and teledensity of users. The RE defining similar radio propagation characteristics is grouped by macro cell, micro cell, pico cell and hot spot. ITU-R M.1768 conducts a survey on the broadband wireless communications-related research institutes or companies, and uses the questionnaire data such as user density, session arrival rate, mean service bit rate, average session duration, mobility ratio to predict future traffic generation.

Radio access technology group is divided into 4 groups like RATG1(pre IMT-2000, IMT-2000 and its enhancements), RATG2(IMT-Advanved), RATG3(existing radio LAN) and RATG4(digital mobile broadcasting systems). Each group defines technical parameters about center frequency, one-way

delay, maximum data rate, guard band, spectral efficiency, duplex, data rate at cell boundaries, types of service, carrier bandwidth, availability of p-to-p, flexible spectrum use. But we don't care about RATG3 and 4 because these categories are not agreed on its utilization at ITU.

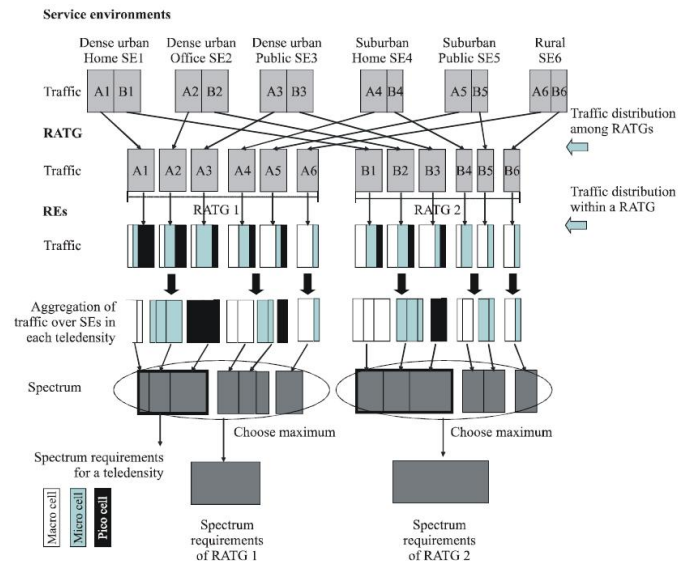


Figure 1. Traffic distributions among SEs, RATGs, and REs

Figure 1 explains the frequency requirements estimation procedure of ITU-R M.1768. Primarily, traffic obtained through analysis of market data is sorted out according to service categories and service environment. The sorted traffics are re-distributed into RATGs and radio environment categories. Aggregation of traffics in teledensity splits into three criteria; dense urban, suburban, rural. System capacity is defined as traffic throughput satisfying QoS of service category by teledensity(d), RATG(rat), radio environment(p). It is separately calculated by circuit switching system and packet switching system like following equation (2).

$$C_{d, rat, p} = C_{d, rat, p, cs} + C_{d, rat, p, ps} \quad (2)$$

Teledensity, RATG, radio environment specific frequency requirement is expressed by following equation (3). $\mu_{d, rat, p}$ means spectral efficiency.

$$F_{d, rat, p} = \frac{C_{d, rat, p}}{\mu_{d, rat, p}} \quad (3)$$

If there is multiple cells in the same teledensity, the frequency requirements of each environment are added up. But because pico cell and hot spot don't co-exist, so consider the maximum value of two values.

$$F_{d, rat} = F_{d, rat, macro} + F_{d, rat, micro} + \max(F_{d, rat, pico}, F_{d, rat, hotspot}) \quad (4)$$

Processing on teledensity is divided regionally, so the maximum value is selected by equation (5). The total frequency requirements on various RATGs is added up according to equation (6) because the RATGs are used in same time and same region.

$$F_{\text{rat}} = \max_d(F_{d,\text{rat}}) \quad (5)$$

$$F = \sum_{\text{rat}} F_{\text{rat}} \quad (6)$$

III. PROPOSED BANDWIDTH ESTIMATION METHOD

It isn't appropriate to adopt above mentioned bandwidth estimation methods for wireless railway communication system. In case of ITU-R M.1380, that could not reflect diverse service property required by integrated train control system because of its procedural simplicity. On the other hand, the ITU-R M.1768 is too complex to apply in our specific case because this methodology considers multiple RATGs though we consider only one RATG in this paper. So a negotiated method of ITU-R M.1380 & 1768 is presented at this section optimizing bandwidth estimation of wireless railway communication system.

In geographic consideration stage, the service environment type is divided in station building and track. Since we have to consider the region occurring maximum traffic primarily, the track environment is ignored. And, the shape of cell is assumed to be an ellipse. At the market and traffic consideration stage, the railway communication traffics are classified into two categories as speech(S), data(D), image(I) and vital(V), non-vital(N). In railway service, the number of users such as trains, station employees, devices for railway could be investigated clearly. In technical system considerations stage, the concept of session arrival rate and service activity mentioned at ITU-R M.1768 is adopted into traffic calculation procedure. Eventually, weighting factor and adjustment factor is modified according to the characteristics of the railway service at the spectrum result considerations stage.

To determine the bandwidth requirement estimation scenario, the parameter based on seoul station, the most crowded station in korea, were investigated. Seoul station consists of three general train courses and three subway courses. But radio environment is sheltered each other, so a separated base station can be used in this situation. Because of that, we consider traffics of the general train course only in this paper.

The safety distance for braking is set to 1400m for general trains running over 100km/h and 600m for wide-area trains running relatively slowly(The safety distance is reduced 8.35% every five years). D denotes the current time(2012), and D+5 for the year of 2017 and D+10 for 2022.

TABLE 1. ANNUAL CHANGE OF TRAIN SAFETY DISTANCE FOR BRAKING

Train type	Train safety distance for braking		
	D	D+5	D+10
General train	1400m	1283m	1166m
Wide-area train	600m	550m	500m

Table 2 represents maximum train number in 2km cell installed at seoul station. To calculate the number of train in single cell, equation (7) is used. N denotes the number of train, C denotes the number of course. And '2' means going and returning.

$$N_{\text{single cell}} = \{N_{\text{single course}} \times C_{\text{number of course}} \times 2\} + N_{\text{waiting}} \quad (7)$$

TABLE 2. THE NUMBER OF TRAINS IN EACH COURSE

Train type	The number of trains in each course		
	D	D+5	D+10
General train	2	2	2
Wide-area train	0	4	5

TABLE 3. ANNUAL MAXIMUM NUMBER OF TRAINS IN SINGLE CELL

Annual maximum number of trains in single cell		
D	D+5	D+10
22	30	36

Following table 4,5 defines downlink & uplink service categories[3] and parameters necessary for bandwidth estimation such as transmission period, delay time, priority, datarate. 'U' denotes services for uplink, 'D' for downlink. And V denotes property 'Vital', N denotes 'Non-vital'. Datarate '0' means unimplemented service at the current time, or there is no plan about implementation of corresponding service in the future..

TABLE 4. THE CHARACTERISTICS OF SERVICES

service	Detail of service	Transmission period	Delay time	Priority
Train control	Transmission of train speed control(D)	Real-time	35~280ms	V
	Transmission of train interval control(D,U)	Event	35~280ms	V
	Transmission of train location(U)	Real-time	35~280ms	V
Monitoring of running train status and railway device	Real-time train status monitoring(U)	Real-time	35~280ms	V
	Railway infra monitoring(U)	Real-time	35~280ms	V
	Railway device monitoring(U)	Real-time	35~280ms	V
	Railway safety device monitoring(U)	Real-time	1s	V
	Train/device status transmission(U)	Event	0.5s	V
Video detection system	Safety support using platform video(D)	Event of train entering	0.5±0.1s	V
	Crime prevention in conjunction with maintenance system(D,U)	Event	0.5±0.1s	V
	Security maintenance using station video(U)	Real-time	0.5±0.1s	N
	Safety maintenance using video within the	Response absence	0.5	V

	cab(U)		$\pm 0.1s$		& maintenance of train	communication(D,U)			
	Safety maintenance using video within the vehicle(U)	Real-time	0.5 $\pm 0.1s$	V		Station wireless communication(D,U)	16	16	16
	Propagation in the event of accident(U)	Event of accident	0.5 $\pm 0.1s$	V		Portable wireless communication(D,U)	16	16	16
						Vehicle wireless communication(D,U)	16	16	16
Operation & maintenance of train	Commander wireless communication (D,U)	Traffic accrual basis	0.5 $\pm 0.1s$	V	Railway customer service	Vehicle passenger service(D,U)	13.75	13.75	13.75
	Station wireless communication (D,U)	Traffic accrual basis	0.5 $\pm 0.1s$	V	Freight information management	Tracking cargo movement path(D,U)	14	14	14
	Portable wireless communication (D,U)	Traffic accrual basis	0.5 $\pm 0.1s$	V		Real-time information confirmation in CY(D,U)	14	14	14
	Vehicle wireless communication (D,U)	Traffic accrual basis	0.5 $\pm 0.1s$	V	Railroad crossings information system	Crossing control information system(D,U)	14	14	14
Railway customer service	Vehicle passenger service(D,U)	Rail-time around the station	0.5 $\pm 0.1s$	N		Crossing observation system(D)	2000	2000	2000
Freight information management	Tracking cargo movement path(D,U)	Rail-time around the station	0.5 $\pm 0.1s$	N					
	Real-time information confirmation in CY(D,U)	CY-site limited	0.5 $\pm 0.1s$	N					
Railroad crossings information system	Crossing control information system(D,U)	Crossing adjacent region limited	0.5 $\pm 0.1s$	V					
	Crossing observation system(D)	Crossing adjacent region limited	0.5 $\pm 0.1s$	V					

TABLE 5. THE DATARATE OF SERVICES

service	Detail of service	Data rate (kbps)		
		D	D+5	D+10
Train control	Transmission of train speed control(D)	12	12	12
	Transmission of train interval control(D,U)	0	0	0
	Transmission of train location(U)	12	12	12
Monitoring of running train status and railway device	Real-time train status monitoring(U)	2000	2000	2000
	Railway infra monitoring(U)	14	14	14
	Railway device monitoring(U)	14	14	14
	Railway safety device monitoring(U)	14	14	14
Video detection system	Train/device status transmission(U)	0	0	0
	Safety support using platform video(D)	2000	2000	2000
	Crime prevention in conjunction with maintenance system(D,U)	0	0	0
	Security maintenance using station video(U)	2000	2000	2000
	Safety maintenance using video within the cab(U)	2000	2000	2000
	Safety maintenance using video within the vehicle(U)	0	2000	2000
	Propagation in the event of accident(U)	2000	2000	2000
Operation	Commander wireless	16	16	16

DL/UL traffics are consists of data traffic for train control, voice traffic for command and maintenance, video traffic for observation. Especially data traffics are characterized by the parameter 'session arrival rate γ ' and 'service activity δ '. Session arrival rate represents the number of train penetration per second at busy hour in the majority of cases. And service activity parameter means the time variable about how long the service maintains when it starts. Session arrival rate parameter increases depending on the rising number of train in one single cell. Data service traffic is calculated by the equation (8). R denotes datarate of corresponding service.

$$C_{data} = R_{service} \times \gamma_{service} \times \delta_{service} \times N_{user} \quad (8)$$

Following table 6 shows DL data service characteristic.

TABLE 6. DOWNLINK DATA SERVICE CHARACTERISTICS OF 2012

Year	D (2012)			
	Datarate (kbps)	Session arrival rate	Service activity	Service Priority
Train speed control	12.0	1.0000	1.0000	V
Service for passenger	13.8	0.0458	8.0000	N
Tracking cargo movement path	14.0	0.0417	0.0366	N
Real-time cargo handling information	14.0	0.0417	0.0366	N
Crossing control information system	12.0	0.0153	45.0000	V

Following table 7 represents the characteristics of DL/UL voice services. In wireless railway communication system, we

assume utilization of VoLTE for voice service(45.6kbps transmission format). Blocking probability parameter means QoS offered to users, and voice activity parameter represents the time ratio of actual voice transmission in entire calling time. Required channel is the number of channels to process occurred voice erlang guaranteeing at least blocking probability. Because of additional course installation, the number of users in single cell increases. Accordingly, the required number of channels in the future increases, too.

TABLE 7. DL/UL VOICE SERVICE CHARACTERISTICS OF 2012

Year	D (2012)					
service	Data rate	Voice activity	Req.Ch	Erlang Per user	Blocking probability	N of subscriber
Command	45.6	0.38	13	0.20	0.001	22
Station operation	45.6	0.38	29	0.20	0.001	78
Mobile	45.6	0.38	11	0.10	0.001	35
For vehicle	45.6	0.38	13	0.10	0.010	66
Police	45.6	0.38	5	0.10	0.001	5

Using the parameters mentioned above, maximum traffic of wireless railway communication in case of 2km cell diameter. Table 8,9 represents the entire amount of traffic and composition status of each service. The type of service is classified as criterion of data(D), voice(S), video(I) and priority such as vital, non-vital. Total amount of traffic is summed up depending on the duration D, D+5, D+10. The amount of DL traffic is greater than UL traffic at the present time, but uplink video data transmission is significantly increased compared to downlink in the future. Because of that, the total amount of traffic is also greatly increased.

TABLE 8. DL TRAFFIC OCCURRENCE VARIATION

Year	D (2012)		
Classification	Traffic (kbps/cell)	Traffic (kbps/cell)	Traffic (kbps/cell)
service	Data	2,467.5	3,574.8
	Voice	1,230.3	1,386.2
	Video	3,666.7	5,000.0
Total	7,364.4	9,961.0	12,192.0
Priority	Vital	6,396.2	8,677.9
	Non-vital	968.2	1,283.1
Total	7,364.4	9,961.0	12,192.0

TABLE 9. UL TRAFFIC OCCURRENCE VARIATION

Year	D (2012)		
Classification	Traffic (kbps/cell)	Traffic (kbps/cell)	Traffic (kbps/cell)
service	Data	1,444.7	2,065.4
	Voice	1,230.3	1,386.2
	Video	1,200.0	9,500.0
Total	3,875.0	12,951.7	15,757.3
Priority	Vital	2,906.8	9,623.2
	Non-vital	968.2	3,328.5
Total	3,875.0	12,951.7	15,757.3

Table 10 is expected spectral efficiency value of various mobile communication systems. Because a technological advance of WCDMA reached the limits, there is no more investment to it.

TABLE 10. SPECTRUM EFFICIENCY VARIATION OF EACH SYSTEM

	Annual spectrum efficiency variation		
System	D	D+5	D+10
WCDMA	0.30	1.00	1.00
LTE	1.70	1.92	2.14
WiBro	0.65	1.30	1.30

IV. CONCLUSIONS

Frequency requirements of integrated wireless railway communication system based on LTE is calculated through dividing DL/UL traffic occurrence(Table 8,9) by spectrum efficiency of LTE(Table 10). Following table 11 represents sum of frequency requirement estimation. The amount of entire frequency requirement is increased less than increased traffic. That is because of spectral efficiency rise through advance of LTE technology.

TABLE 11. ANNUAL FREQUENCY REQUIREMENT VARIATION OF WIRELESS RAILWAY COMMUNICATION

	Frequency requirement (MHz)		
Direction	D	D+5	D+10
Downlink	4.33	5.19	5.70
Uplink	2.28	6.75	7.36
total	6.61	11.94	13.06

Present frequency requirement of wireless railway communication of vital for vital service is DL 3.76MHz and UL 1.71MHz. If we consider non-vital services to supply additional services, DL 4.33MHz and UL 2.28MHz should be prepared. To design railway communication system, more than 10 years should be considered because of its utilization terms and construction costs. 10 years later, expected frequency requirement to support only vital service is 4.95MHz for DL and 4.82MHz for UL. In case of considering non-vital services, expected bandwidth is DL 5.70MHz and UL 7.36MHz.

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