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Adaptive Wireless Transmission Scheme Considering Stay Time in Spot Mobile Access

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SUMMARY In this paper, an adaptive transmission scheme considering the stay time in a spot mobile access system is proposed. The proposed adaptive transmission scheme selects the modulation format according to the user's stay time in the spot communication zone and the types of data requested by each user. In the proposed system, when the stay time of a user is short, high-speed modulation is selected for this user. When the stay time of a user is long, a more reliable modulation format is selected. The computer simulation results show that the proposed transmission scheme without any channel estimation can achieve the same or better performance than when using the modulation format fixedly when the carrier-to-noise ratio changes rapidly.
key words: *adaptive transmission, wireless communications, radio resource management, spot access system, radio agent*

1. Introduction

The development of mobile networks enables more flexible communications and easier access to various kinds of information, and it has begun to change our lifestyle. In order to obtain multimedia contents such as from the WWW (World Wide Web), video streaming, and voice service anytime, anywhere, it is required to access them without any restrictions of time or place. A wireless access method can provide mobility to the user as one of the solutions to satisfy this requirement. Currently, cellular phone services comprise the most popular wireless communication system, and various types of services are available such as voice and data transmission over a widespread continuous service area. However, even though a third-generation system such as IMT-2000 (International Mobile Telecommunication), whose maximum transmission rate is 2 Mbps, can achieve a much higher transmission rate than previous cellular systems, this transmission rate is not sufficient compared with the wired networks such as Ethernet.

A wireless spot access system provides high data transmissions in a small local zone. A wireless LAN (Local Area Network) such as IEEE802.11a and g can provide 54 Mbps transmission in a small area. The spot access service using wireless LAN, generally called the hot spot service, has already started at public areas such as airports, stations, and restaurants. The DSRC (Dedicated Short-Range Communication) [1] system which is developed as a part of ITS (Intelligent Transport System) can provide many services such as VICS (Vehicle Information and Communication System) and ETC (Electric Toll Collection System). The system uses the RVC (Road to Vehicle Communication) system. In the early DSRC system, the communication zone was divided into many small spots in order to minimize the cost of constructing the communication system.

In the spot mobile access environment, the available bandwidth for each user is insufficient particularly when many users request data at the same time. Furthermore, we must consider the severe restriction of a user's stay time, the limited period that the mobile terminal is expected to stay in a particular spot [2], [3]. For example, in the RVC system, when the terminal in a vehicle goes through the spot at high speed, its stay time is only a few seconds. In such a short stay time, it is difficult to complete the service, and the signal quality will be increasingly disturbed when using conventional spectral efficient wireless techniques such as multilevel QAM (Quadrature Amplitude Modulation).

In order to improve the frequency utilization efficiency, the use of spectral efficient modulation formats such as 16QAM and 64QAM is ordinarily known. These modulation formats can realize high-speed transmission in narrow bandwidth channels. However, these are more sensitive to additive noise and fading. The adaptive modulation scheme [4], [5] estimates the state of the radio channel and selects a modulation format considering this parameter. When the condition of the radio channel is good, it chooses high-speed modulation such as 64QAM in order to improve the frequency utilization efficiency. However, it requires a feedback channel to send the channel state information from the terminal to the base station.

Recently, in Ref. [6] an adaptive transmission scheme suited for a cellular network has been proposed. This transmission scheme categorizes data traffic to three types, "Voice Phone," "File transfer," and "Interactive Video," and supports the QoS (Quality of Service) control according to the characteristics of each data type. However, this transmission scheme is not suitable for the spot mobile access system because this system assumes a continuous zone such as a cellular network.

In Ref. [7], bandwidth reservation for retransmission to support the QoS of real-time data has been proposed. The scheme can guarantee the QoS when the number of users changes slowly. Therefore, this scheme cannot be applied to the spot mobile access system because the number of users changes rapidly.

In Ref. [8], adaptive prefetch scheme in the spot mobile

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environment has been proposed. This transmission scheme selects a modulation format according to the access probability and data size of prefetched WWW data. It can reduce the latency time to complete the user's request. However, if many users request data at the same time, it is difficult for this scheme to achieve efficient utilization of the radio frequency.

As a resource management protocol, the IEEE 802.11e working group is currently developing a standard to provide the QoS control capability in IEEE802.11a and IEEE802.11b wireless LAN. However, its final draft has not been released. Whitecap2 [9] is a protocol based on the IEEE802.11e. It gives priority to the real-time traffic assigning much bandwidth to high-priority packets. This protocol supports QoS for real-time data, however we must consider the improvement of service quality even for non-real-time data, such as WWW documents and image files in the spot mobile access system.

The transmission schemes mentioned above have not considered the severe restriction of stay time even though it is a critical problem in spot mobile access systems. Therefore, they are not suitable for the spot mobile access system. In this paper, we propose a new type of adaptive transmission scheme considering stay time in the spot mobile access system, which is capable of improving the bandwidth utilization efficiency. The proposed scheme selects a modulation format according to both the user's stay time and the type of data. The proposed transmission scheme without any channel estimation technique can achieve the same or better performance than conventional scheme using a fixed modulation format when the channel CNR (Carrier-to Noise-power-Ratio) changes extremely rapidly.

In the following, Sect. 2 describes the system model and the proposed adaptive transmission scheme, and in Sect. 3, a computer simulation evaluates the performance of the proposed scheme. Section 4 concludes this paper.

2. System Description

2.1 Transmission Procedure of the Proposed Scheme

Figure 1 illustrates the system model of the RVC system configured with spot mobile access. The base stations (BSs) are connected via the Internet through the center station. If a user requests data, the center station downloads the data from the WWW server with TCP/IP. The center station sends the data to the base station accommodating the user. Then at the base station, the requested data are transferred to the user through the wireless channel with the profiled protocol over DSRC. In the proposed transmission scheme, the radio agent equipped at the center station chooses some wireless transmission parameters suitable for the situation of each user in order to send all the data within the available stay time in a spot. A RF carrier is modulated based on the transmission parameters decided by the radio agent.

Figure 2 shows the block diagram of the proposed system. When a vehicle arrives at a spot, the speed estimator

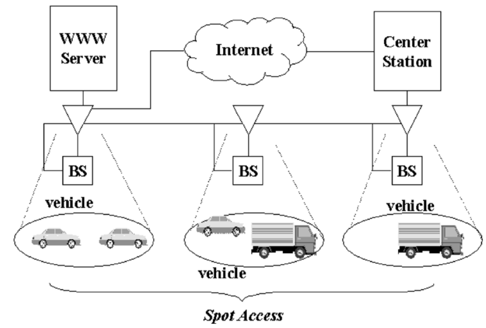


Fig. 1 Model of RVC system.

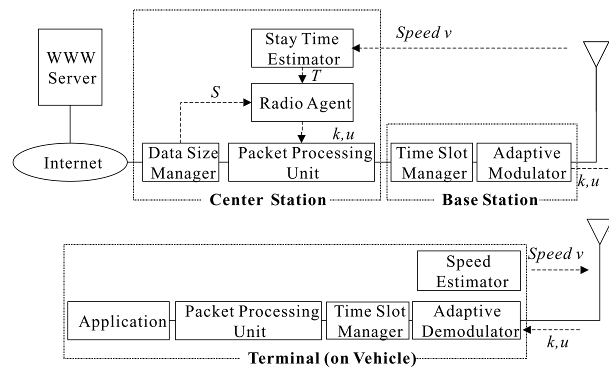


Fig. 2 Block diagram of the proposed system.

on the vehicle estimates its speed. In the proposed transmission scheme, the vehicle uploads its vehicle speed v obtained from the speedometer to the stay time estimator via an uplink. The stay time estimator located at layer 7 in the center station estimates the user's stay time, T [s], given by $T\,[\mathrm{s}] = L\,[\mathrm{m}]\,/v\,[\mathrm{m/s}]$, where L is the estimated length of the communication zone. Next, the estimated stay time is sent to the radio agent. Then, the data size manager estimates the data size of the requested data, S, and sends the data size to the radio agent. Based on these data, S and T, the radio agent allocates time slots, u, and modulation format, k, to the user and relays them to the packet processing unit by means of the header of each transmitted packet. At the base station, according to the modulation format and the allocated number of time slots attached to the packet header, the data modulates a RF carrier and is sent to the vehicle in the allocated slots. The terminal at each vehicle demodulates the received data at the adaptive demodulator. The time slot manager and the packet processing unit reconstruct the original application data from the received packets.

2.2 Proposed Adaptive Transmission Algorithm

In this section, we describe the algorithm of the proposed adaptive transmission scheme. Assuming that n users request data at the same time, u_i $(i = 1, 2 \ldots n)$ denotes the number of time slots allocated to the ith user. In this transmission scheme, we use dynamic TDM (time division multiplexing) with U time slots, and allocate time slots equally to the users requesting data. For example, if two users request data ($n = 2$), the proposed scheme allocates half of the total time slots to each user ($u_1 = u_2 = U/2$).

Next, the proposed scheme estimates the stay time ΔT_i [s] ($i = 1, 2 \ldots n$) and ith data size ΔS_i [bytes] ($i = 1, 2 \ldots n$), for n users. ΔT_i is the rest of the stay time until the ith user leaves the spot. ΔS_i is the rest of the requested data for the ith user which should be transmitted within the stay time ΔT_i. Then the radio agent calculates the required transmission rate, R_i [bps/Hz], for the ith user, which is the transmission rate to complete the request within stay time ΔT_i in the situation that all the usable bandwidth Δf [Hz] is equally shared by n users. R_i is given by

$$R_i = n \times \frac{\Delta S_i}{\Delta f \times \Delta T_i} \quad (i = 1, 2 \ldots n), \tag{1}$$

R_i indicates the required modulation level of the M-ary QAM format to finish the transmission of the requested data during the stay time ΔT_i. The R_i is normally a real number while the modulation level of 2^{k_i}-QAM has a discrete value, $2, 4 \ldots 2^{k_i}$. Therefore, to maximally reduce the transmission error against additive noise and fading, the radio agent divides the stay time ΔT_i into Δt_i and $\Delta T_i - \Delta t_i$, and also assigns each of two modulation formats, 2^{k_i}-QAM and $2^{(k_i+2)}$-QAM to Δt_i and $\Delta T_i - \Delta t_i$, respectively, in order to attain the R_i for the ith user. For example, when $R_i = 2.4$, QPSK and 16QAM are selected ($k_i = 2$). QPSK is a more reliable modulation format than 16QAM, while 16QAM is more spectrally efficient than QPSK. The adequate set of the minimum value of k_i and maximum value of Δt_i for the ith user can be found from

$$R_i \le \frac{k_i \Delta t_i + (k_i + 2)(\Delta T_i - \Delta t_i)}{\Delta T_i} \quad (i = 1, 2 \ldots n), \tag{2}$$

This algorithm can realize a more reliable modulation format for each user during a larger time Δt_i as long as there is usable bandwidth, and after that, a more spectrally efficient modulation format is used to finish transmitting all the data within their stay times, $\Delta T_i - \Delta t_i$.

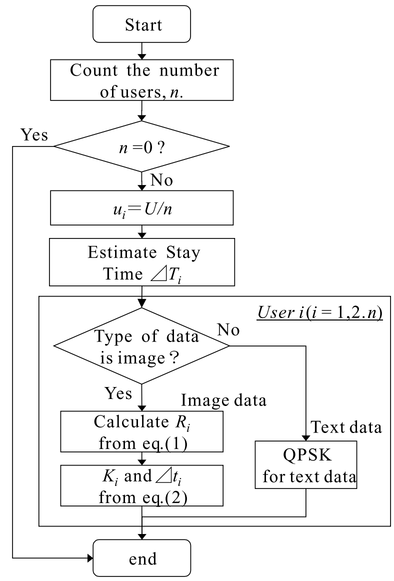


Fig. 3 Flowchart of the proposed algorithm.

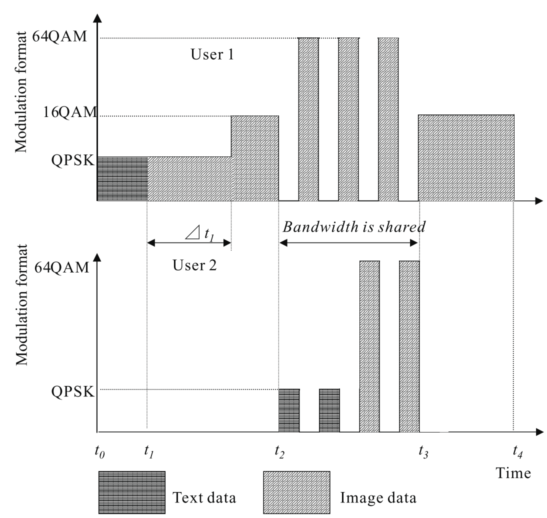


Fig. 4 Example of the procedure of the proposed algorithm.

2.3 Application for Text and Image Data Downloading

In the following section, we assume that each user requests a document consisting of text and image data. Figure 3 shows the flowchart of the proposed algorithm for the assigning the modulation format, k, and time slots, u, when the number of the requested users is n. First, the radio agent counts the number of users n, and assigns TDM slots according to n. For example, when only one user exists in a spot, all TDM slots, U, are allocated to this user, on the other hand, when two users exist in a spot, half of all TDM slots, $U/2$, are allocated to each user. Then, the radio agent receives the estimated stay time of each user, ΔT_i ($i = 1, 2 \ldots n$), from the stay time estimator.

In the next procedure for each user, the radio agent selects the modulation format according to stay time, ΔT_i, and the assigned time slot, u_i. At the first step of this procedure, the radio agent judges the data type: text data or image data. If the data type is text, the radio agent selects QPSK as a modulation format in order to transmit text data with as a low bit error rate as possible. On the other hand, if the data type is image, the radio agent calculates the required transmission rate, R_i, from Eq. (1) and selects the modulation format, k_i, used during the period, Δt_i, and $k_i + 2$ used during $\Delta T_i - \Delta t_i$ to satisfy Eq. (2).

After these procedures, the requested data are transmitted to each user. This algorithm is re-started whenever the number of users changes, that is, a user's entire request is completed, the user leaves a spot, or a new user arrives at the spot.

Figure 4 illustrates an example of the procedure of the proposed scheme. User 1 and User 2 stay in $t_0 \sim t_4$ and $t_2 \sim t_3$, respectively. User 1 can use all the bandwidth, that is, TDM time slots, until t_2 and receives the text with only QPSK and image data with QPSK and 16QAM formats respectively. Because User 1 has sufficient stay time, the image data is transmitted with 16QAM after QPSK transmission during Δt_1. When User 2 arrives at t_2, two users must share the bandwidth. Therefore, the proposed scheme selects a more spectral efficient modulation format, 64QAM, to transmit image data to both users while the text data for User 2 is transmitted with reliable QPSK. User 2 leaves the spot at t_3, User 1 can use all the bandwidth again and the proposed scheme selects 16QAM.

3. Performance Evaluation

3.1 Simulation Parameters

In this section, we evaluate the service probability performance of the proposed scheme in a spot mobile communication environment, by computer simulation. We define the service probability,

$$P_s = \frac{N_c}{N_a} \tag{3}$$

where N_c denotes the number of users for whom their requests are completed correctly within their stay times and N_a is the total number of users. Table 1 shows the parameters used in this simulation. In this simulation, we assume the situation that every user requests the same HTML (hypertext markup language) documents, such as road information including text and image data the sizes of which are 150 [kbytes] and 1350 [kbytes], respectively. We also assume that the time interval between user arrival and the stay time of each user follows an exponential distribution. The spot length is set to 50 [m], which covers three lanes. The frequency and its bandwidth are based on the DSRC standard. The rice fading channel is assumed in a wireless environment and the average channel CNR is assumed to be the same in every lane.

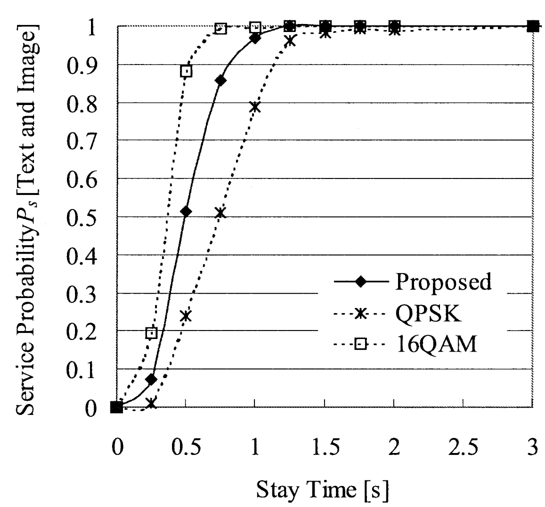
Table 1 Computer simulation parameters.

Channel model	Rice fading channel (k=5 [dB])
Frequency band	5.8 GHz
Bandwidth Δf	2 MHz
Maximum normalized Doppler Frequency $f_d T_s$	2.67×10^{-4}
Stay time of user	Exponential distribution (Ave 2.0 [s])
Arrival interval of user	Exponential distribution (Ave 5.0 [s])
Image data size	1350 [kbytes]
Text data size	150 [kBytes]
Spot length	50 [m]
Maximum vehicle speed	100 [km/h]
Maximum number of users n	8
Multiple format (downlink)	Dynamic TDM
Modulation format	QPSK/16QAM/64QAM
ARQ type	Stop and wait

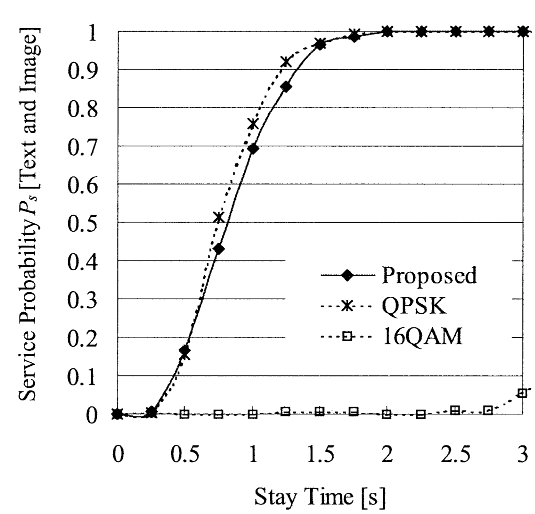
3.2 Service Probability Performance versus Stay Time

3.2.1 Service Probability Performance for All Data

Figures 5(a) and (b) show the service probability performance for all the requested data, including text and image data, versus stay time for mean CNR of 35 [dB] and 20 [dB], respectively. The ordinate P_s [Text and Image] shows the probability that a user can receive text and image data completely. For comparison, Fig. 5 also shows the service probability performance when all terminals, which are equally allocated the same bandwidth, use the same modulation format, QPSK or 16QAM. It is seen from Fig. 5(a) that for the short stay time, the proposed scheme can improve the performance than using QPSK only. However, the conventional scheme using 16QAM only exhibits the best perfor-



(a) Channel CNR=35[dB]



(b) Channel CNR=20[dB]

Fig. 5 Service probability performance for all the requested data versus stay time in rice fading channel. The performance using QPSK or 16QAM fixedly is also plotted on this figure.

mance. For example, when the stay time of a user is 1.0 [s], the service probability performance of the proposed scheme is 97%, while the performances of the conventional scheme QPSK, 16QAM, are 78% and 100% respectively. This is because the bit error rate of 16QAM at CNR=35 [dB] is sufficiently low to transmit the requested data correctly. However, it is seen from Fig. 5(b) that the proposed scheme gives a better performance at CNR=20 [dB]. When the stay time is 1.0 [s], the service probability performance of the proposed scheme is 72%, while the performances of the conventional scheme QPSK and 16QAM are 78% and 0%, respectively. This is because the error rate performance of the 16QAM at CNR=20 [dB] is not good enough to transmit the data correctly and the frequent retransmission of the requested packets prevents users from completing their requests. In the RVC system, average CNR varies depending on shadowing or position of terminals. Therefore it can be expected that the proposed scheme exhibits a better performance than the conventional scheme when channel CNR changes rapidly. We discuss this in detail in Sect. 3.3.

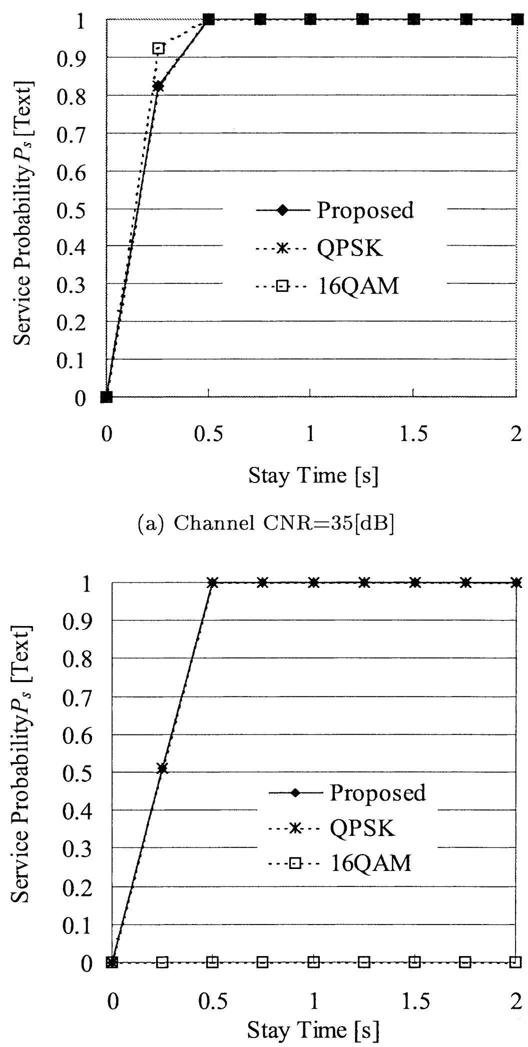
3.2.2 Service Probability Performance for Text Data

Assuming road information to be the requested document, the text data should be received as reliably as possible. In this section, we focus on the service probability performance for text data versus stay time.

Figures 6(a) and (b) show the service probability performance for text data versus stay time for the channel CNRs of 35 [dB] and 15 [dB]. The ordinate P_s [Text] shows the probability that a user can receive the text data completely. For comparison, Figs. 6(a) and (b) also show the performance of allocating the bandwidth equally to all terminals and using QPSK or 16QAM modulation format. It is found from Fig. 6(a) that for that high CNR, both the proposed scheme and the conventional scheme using QPSK or 16QAM show almost the same performance even when the stay time is short. This is because the channel CNR is sufficiently good and the data size of the text data is small. However, Fig. 6(b) for the low CNR shows that when the stay time is 1 [s], the service probability performance of the proposed scheme and the conventional scheme using QPSK is 100% while the performance of the conventional scheme 16QAM is 0%.

3.3 Service Probability Performance versus Channel CNR

Figure 7 shows the service probability performance for text and image data versus channel CNR. In this figure, we also show the performance of allocating the bandwidth equally to all terminals and selecting the modulation format fixedly as QPSK or 16QAM. When the channel CNR is higher than 30 [dB], conventional 16QAM scheme shows the best performance. However, it rapidly deteriorates as CNR decreases. At CNR = 15 [dB], the service probability is 0%. However, the proposed scheme exhibits better performance than the conventional QPSK for different values of CNR.



(a) Channel CNR=35[dB]

(b) Channel CNR=15[dB]

Fig. 6 Service probability performance for text data versus stay time in rice fading channel. The performance using QPSK or 16QAM fixedly is also plotted in this figure.

When CNR is higher than 30 [dB], the performance of the proposed scheme is slightly worse than that of 16QAM, but large degradation such as that when we use 16QAM at low CNR is avoidable. This is because the proposed scheme selects a more reliable modulation format when the stay time of a user is long. When channel CNR is lower than 20 [dB], the performance of the proposed scheme is slightly worse than that of conventional QPSK. This is because the proposed scheme assigns a high-speed modulation format to the user when its stay time is short, and it causes frequent retransmission in the low CNR region. However, because the distribution of the stay time and the variation of the channel CNR are independent, the restrictions of the stay time and channel CNR rarely become severe at the same time.

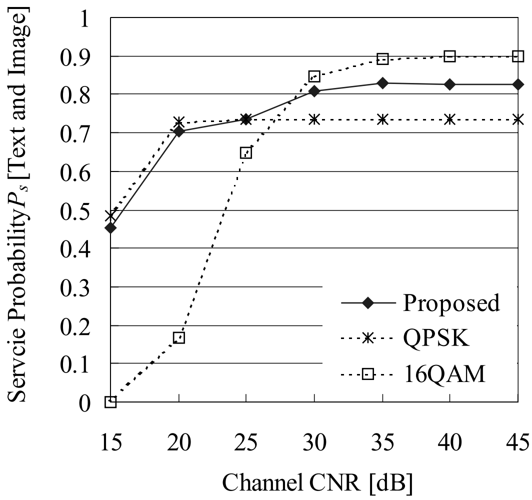


Fig. 7 Service probability performance for text and image data versus channel CNR in rice fading channel. The performances using QPSK and 16QAM fixedly are also plotted in this figure.

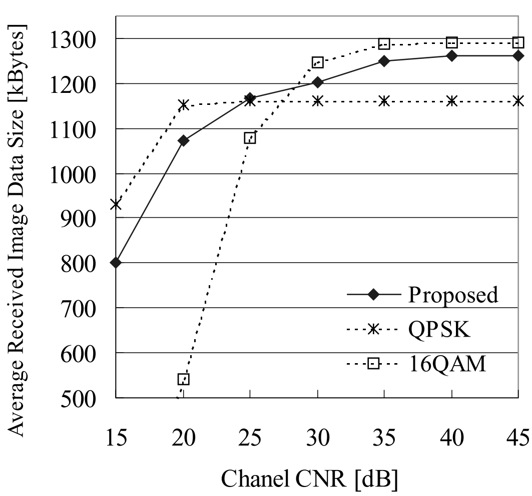


Fig. 8 Average received image data size performance versus channel CNR in rice fading channel. The performance of the proposed scheme and the performance using QPSK or 16QAM fixedly are also plotted in this figure.

3.4 Average Received Data Size Performance versus Channel CNR

Assuming road information to be the requested document, we can utilize this information even when the user receives only part of the requested image data. This is better as we can receive as much image data as possible. In this section, we focus on the average received data size of the image versus channel CNR. Figure 8 shows the average received data size versus channel CNR. The ordinate shows the average received data size of the image. This figure also shows the performance of allocating the bandwidth equally to all terminals and selecting the modulation format fixedly as QPSK or 16QAM. When the channel CNR is higher than 30 [dB], the conventional 16QAM scheme shows the best performance. However, it is rapidly deteriorated as CNR decreases. At CNR = 20 [dB], the average received data size is 540 [kbytes] which is half the performance at CNR =35 [dB]. However, the proposed scheme shows a better performance than conventional QPSK for different values of CNR. When CNR is higher than 25 [dB], the performance of the proposed scheme is slightly worse than that of 16QAM, but large degradation such as that when using 16QAM at low CNR is avoidable. When channel CNR is lower than 20 [dB], the performance of the proposed scheme is slightly worse than that of conventional QPSK.

The result in this section shows that the proposed transmission scheme without any channel estimation can achieve the same or better performance of average received data size than when using the modulation format fixedly when the CNR changes rapidly.

4. Conclusion

We have proposed the adaptive transmission scheme considering the stay time for spot mobile access systems. The proposed scheme estimates the stay time of users and selects an adequate modulation format under the restriction of the stay time. The modulation format is also chosen according to the type of data. It can solve the restriction of stay time with high-frequency utilization efficiency for the spot-type communication system. Assuming the situation that users in vehicles download the same data in one spot, the results of computer simulation have verified that the proposed scheme gives much better performance than conventional one when the stay time of a user is short. The proposed scheme without any estimation of channel CNR exhibits the best performance in the case that the channel CNR is changing depending on the position of terminals or shadowing. The adoption of the proposed management scheme to CSMA/CA access will be a subject of further study.

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