WINMAC: A Novel Transmission Protocol for Infostations

Gang Wu*, Churng-Wen Chu, Kevin Wine, James Evans, and Richard Frenkiel

WINLAB, Rutgers University, 73 Brett Road, Piscataway, NJ 08904

*Communications Research Laboratory, MPT, Japan

E-mail: g-wu@crl.go.jp

Abstract

Infostation is a new system concept proposed to support "many time, many where" wireless data services including voice mail. It allows mobile terminals to communicate to Infostations with variable data transmission rate to obtain the optimized throughput. Three service scenarios can be applied to the system to support mobile terminals access to Infostations, sit through, walk through, and drive through.

In order to handle channel access and allocation, retransmission, and adaptive transmission rate adjustment in Infostation systems, an intelligent transmission protocol called WINMAC is required. With the seven-layer ISO-OSI computer network model, WINMAC covers data link control layer, MAC sublayer and part of physical layer. According to the concept of Infostation and services to be provided, we indicate first the basic requirements and services to be supported by WINMAC.

WINMAC should support multiple access when multiple mobile terminals share the same channel. Then, a contention-based MAC protocol is required. Corresponding to the three scenarios, we define two services, fairness and preemptive, for WINMAC. Fairness service is designed for sit through and walk through scenarios. Multiple mobile terminals are supported to work in fairness state and they share channel resources fairly. On the other hand, preemptive service is designed for walk through and drive through scenarios. It allows single mobile terminal to occupy the channel temporally. During the transmission, the terminal can communicate with Infostations on a variable transmission rate to achieve an effective transmission. To support reliable communication, WINMAC needs to have a link layer retransmission scheme. Also, WINMAC should have functions to support terminals with a variable transmission rate during transmissions.

In this study, we designed the WINMAC for the Infostation prototype being implemented in WINLAB, Rutgers University. The Harris Prism radio chip set designed for 2.4GHz wireless LAN specified by IEEE 802.11 is used as the physical layer equipment. Based on the radio chip set used, we propose the WINMAC to have the following characteristics: asymmetric uplink and downlink transmission structure, fairness and preemptive services support, combined retransmission scheme of selective repeat and go back to N, and variable transmission rate support during service.

A TDMA/TDD channel structure is designed to provide asymmetric uplink and downlink transmission. A TDMA frame includes a number of time slots with the same length in time but different size in bit. In fact, time slots with three transmission rates (i.e., 250Kbps, 1Mbps, and 2Mbps) are supported in a frame. PRMA (Packet Reservation Multiple Access)-TDD is used as the MAC protocol. In fairness service, the channel resource is allocated fairly for the mobile terminals. On the other hand, all the channel resources can be assigned temporarily to a single terminal with a high priority in preemptive service. Since TDMA-TDD is used as the channel structure, a combination of selective repeat and go back to N ARQ scheme with multi-copy technique is designed as the link layer retransmission scheme. Also, a transmission rate switching algorithm is proposed to choose and then switch to the adequate transmission rate.

I. INTRODUCTION

"Anytime, anywhere" is an advertisement for cellular systems used by all service providers. But it is true for cellular systems today (first and second generations) and perhaps tomorrow (third generation) which are mainly designed for voice communications. When people are familiar with Mbps to Gbps wireline Internet services, they will not satisfy the Kbps data transmission service being provided by mobile communication operators, which has a compatible rate with voice transmissions. However, it is not possible for operators to provide the Mbps service to everyone at "anytime and anywhere" due to the limitation of frequency bandwidth, technical difficulties, and economical reasons. On the other hand, typical today's data services such as web surfing, file transferring, voice messaging, email and fax are alternatives that return some control of time and place to the user, which may account for their dramatic growth. The technology for mobile communications of the day after tomorrow (fourth generation) should support high-speed and high-quality services at "many-time many-where."

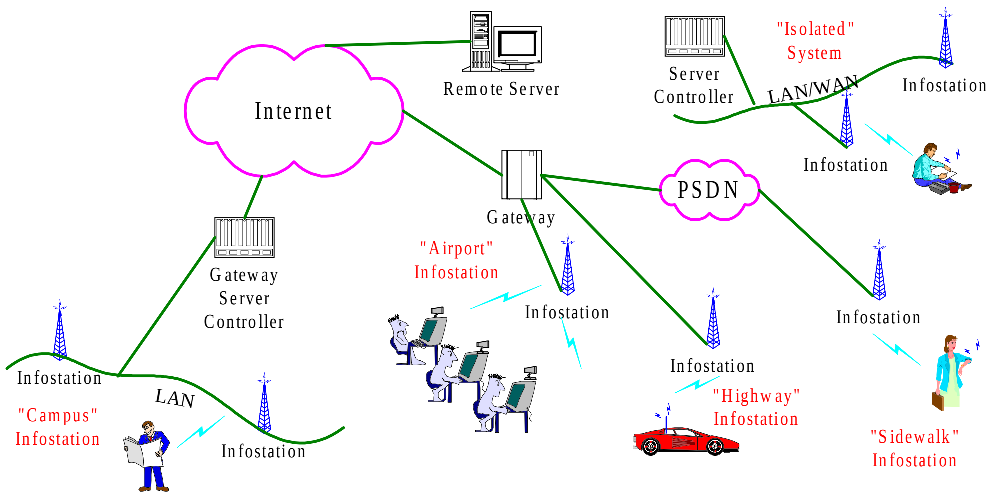

Fig.1 Infostation System Architecture

Fortunately, the concept of Infostations has been proposed [1][2][3] for providing convenient and frequent access to high bit-rate connections. This "many-time many-where" communication is well suited to messaging and can over a wide range of useful and economical services. Fig.1 shows the system architecture of Infostations [1]. Although in general the coverage area of an Infostation is not necessarily defined to be isolated to that of others, isolated Infostations are considered in most of previous studies as well as in this paper.

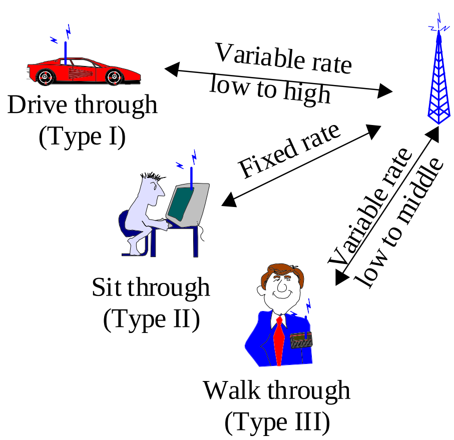

Fig. 2. Three scenarios of user mobility

There are various applications of Infostations that can be described by three basic scenarios of user mobility: drive-through, walk-through, and sit-through (Fig.2). Sit-through can be treated as the same case as wireless LAN. Users can access to Internet using a fixed transmission rate. Walk-through is

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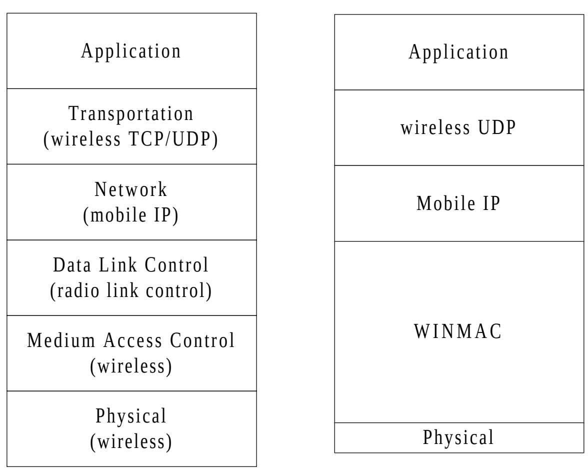
This paper is organized as follows. The general requirements for WINMAC are given in Section II. A special WINMAC designed for a prototype Infostation system and implementation details are described in Section III and Section IV respectively.

II. General Requirements for WINMAC

WINMAC is an intelligent transmission protocol handling channel access and allocation, retransmission, and adaptive transmission rate adjustment for infostations. It covers radio link control, medium access control, and part of physical layers corresponding to the protocol stack for wireless Internet. WINMAC should be able to cope with the three major scenarios considered in an Infostation system: sit through, walk through and drive through. These different scenarios impose different constraints on the protocol and include terminal speed, fading channel, limited coverage area, different user applications and different environments.



The sub-protocol for each layer should be appropriate to fit the three scenarios of Infostations. The sub-protocol of WINMAC for radio link control layer should support *link layer retransmissions* because of the following reasons. The size of a wireless MAC frame is designed to match the channel condition so that it is usually smaller than that of the datagram in network layer, e.g., an IP packet. In other words, an IP datagram is used to be fragmented into a number of wireless MAC frames (WMF). Then, if only one WMF of an IP packet is not correctly received, other WMFs are useless. Thus, the link layer retransmission is required to improve the efficiency of transmissions. Moreover, in the drive-through scenario of Infostations, quick retransmission is very important because the sojourn time passing through an Infostation is very short. Also, the security issue in link control layer, such as authentication, registration, secure transmission, etc. should be taken into account.

The sub-protocol of WINMAC for MAC layer should support multiple access and channel resources allocation. Since the channel is shared by a number of mobile stations, an efficient contention-based MAC protocol is required for registration and/or reservation from multi-users. Also the method of channel resource allocation should be well designed corresponding to requirements on different scenarios. Here we define two kinds of services, *fairness* and *preemptive*, for different scenarios of Infostations. Fairness service is offered for those mobile stations who can stay either in an Infostation coverage area or in Infostation network for a long sojourn time. Sit-through, walk-through and part of drive-through scenarios belong to this service and the channel is shared by many users simultaneously. On the other hand, preemptive service which allow as less as one user to temporarily occupies all the channel resources is offered to the mobile stations who stay with an Infostation for a short sojourn time. Part of walk through and drive through scenarios belong to this service.

The sub-protocol of WINMAC for physical layer should support the automatic transmission rate adjustment. In drive-through and part of walk-through cases, average SNR increases as a mobile goes near to an Infostation if the transmit power does not change. If we adjust the transmit rate to fit the variance of SNR, we can get the optimized system throughput.

III Protocol Design

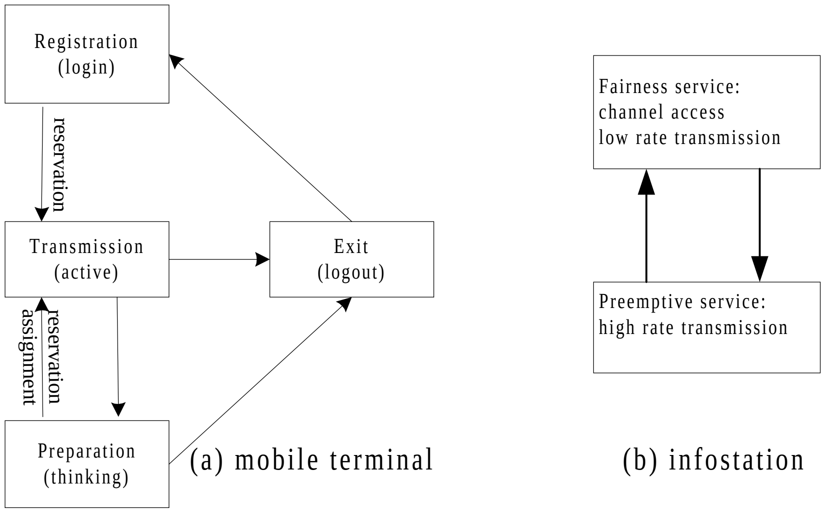
WINMAC is designed for Infostation networks where a mobile terminal may drive through, sit through, or walk through the area covered by an infostation. As a MAC protocol, WINMAC should be able to support multiple access where multi-users contend for access to a shared channel. A variable rate transmission is considered in the infostation system so the WINMAC should support flexible rate switching. Also, the WINMAC should be flexible enough to support both fairness service and preemptive service. Finally, the WINMAC should include an effective retransmission scheme to guarantee the reliability of radio link layer transmission. In a word, the following functions should be offered by the WINMAC.

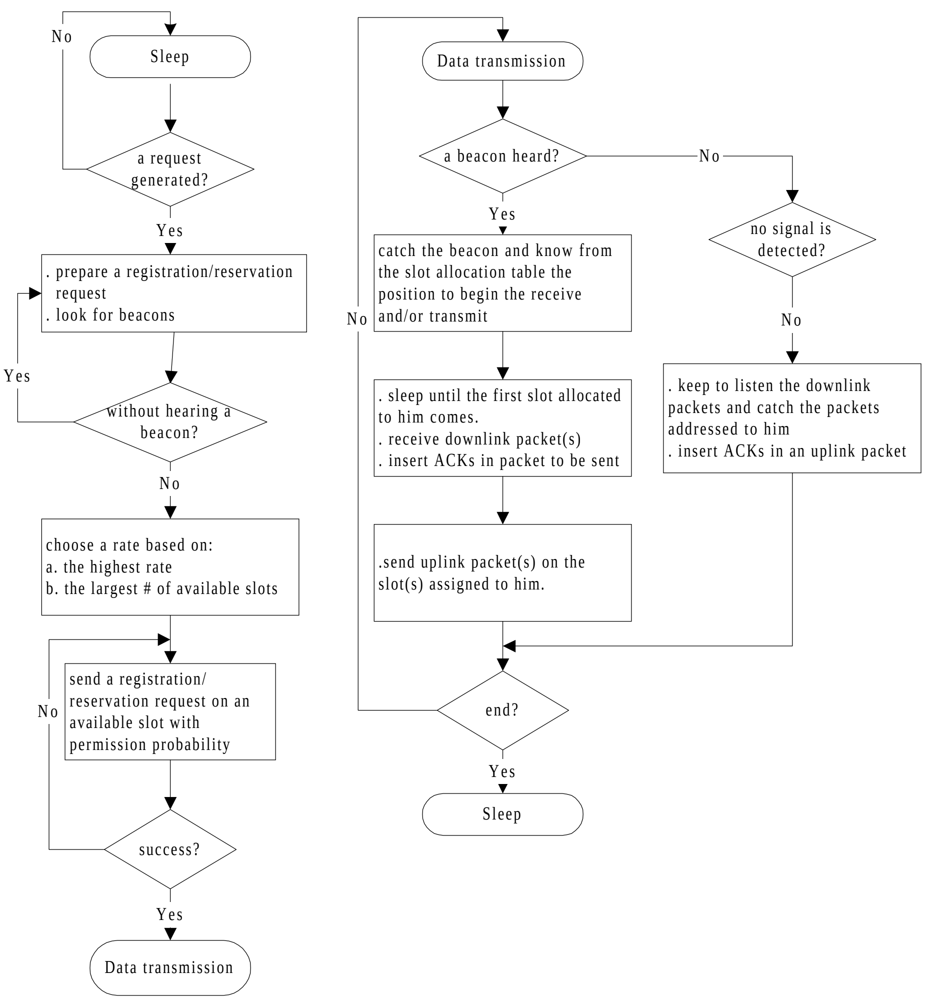
- multiple access and channel resource allocation
- transmission rate switching
- retransmission

1. Multiple Access Protocol

The WINMAC designed for Harris Radio has a TDMA/TDD configuration (see VI). A frame consists of a number of time slots and each slot can carry a packet. As well as PRMA, this MAC protocol has two-step procedure: reservation and transmission and a time slot can be either available for contention or occupied by a specified terminal. The information of slot status can be obtained from the beacons broadcast at the beginning of each frame.

The figure above shows the major operations of a mobile terminal and an infostation. A mobile terminal needs to make a registration at the first time when it drives/walks/sits through an infostation and has a request to transmit. To do this, the terminal should hear the beacons first and choose a rate based on the rule of the highest rate and the largest number of available slots. Then, it transmits a registration request on an available slot by contending with other terminals. After accepting the registration, the infostation will issue an ID for the terminal and the terminal will be working in the transmission state under either fairness service or preemptive service. For some reasons, a terminal may temporarily leave the transmission state (but does not exit) to the preparation state. In the preparation state, a terminal waits for new packets generated from its upper layer or transmitted by the infostation. In the former case, it should make a reservation again by contending for access to the channel. In the latter case, it moves back to the transmission state after hearing the beacons to know a slot assignment made by the infostation. After finishing all the transmission, the terminal exits the infostation. The following flow chart shows the details of the transition of a terminal.





In an infostation, a slot allocation algorithm is working to support fairness service and preemptive service (see details in 3). An infostation is normally working in fairness service state where active terminals share channel fairly. If we do not consider the rate switching issue, the scheme is actually PRMA, or reservation-ALOHA (Of course, one can consider the mini-slot configuration for access. But it is not easy to be implemented currently). Registration is only allowed in fairness service state and thus the admission control is required. The system state moves from fairness service to preemptive service when a user with higher priority appears. In preemptive service state, most of channel resources are assigned to the specified terminal. In each rate, there are at least a pair of uplink and downlink slots reserved for rate switching or something else.

2. Transmission Rate Switching

The transmission rate between the infostation and a mobile terminal can be adjusted to have the throughput maximum. With the Harris Radio, the rate can be one of 250 kbps, 1000 kbps, and 2000 kbps. The possible algorithm for rate switching can be as follows.

2.1 Choosing a Rate

When a terminal makes a reservation by contending for access to the channel, it hears the beacons to choose a rate to send its request. Two factors should be considered when choosing a rate, the highest beacon it heard and the largest number of available time slots.

2.2 Changing Rate from Low to High

2.3 Changing Rate from High to Low

Rate Switching Algorithm

1. Methodology used to make rate switching decision

a) Listen to Beacons of 3 Data Rates

Beacons are good indication of channel condition for what data rate to be used. 2 counters each with window size 3 to cyclically record current and higher rate beacons.

b) Packet Error Rate (PER)

PER of current data rate is good statistical reflection of channel condition. Cyclically record PER for the most recent 3 frames of current rate. Rate Switching Algorithm.

2. Decision making scheme of rate switching

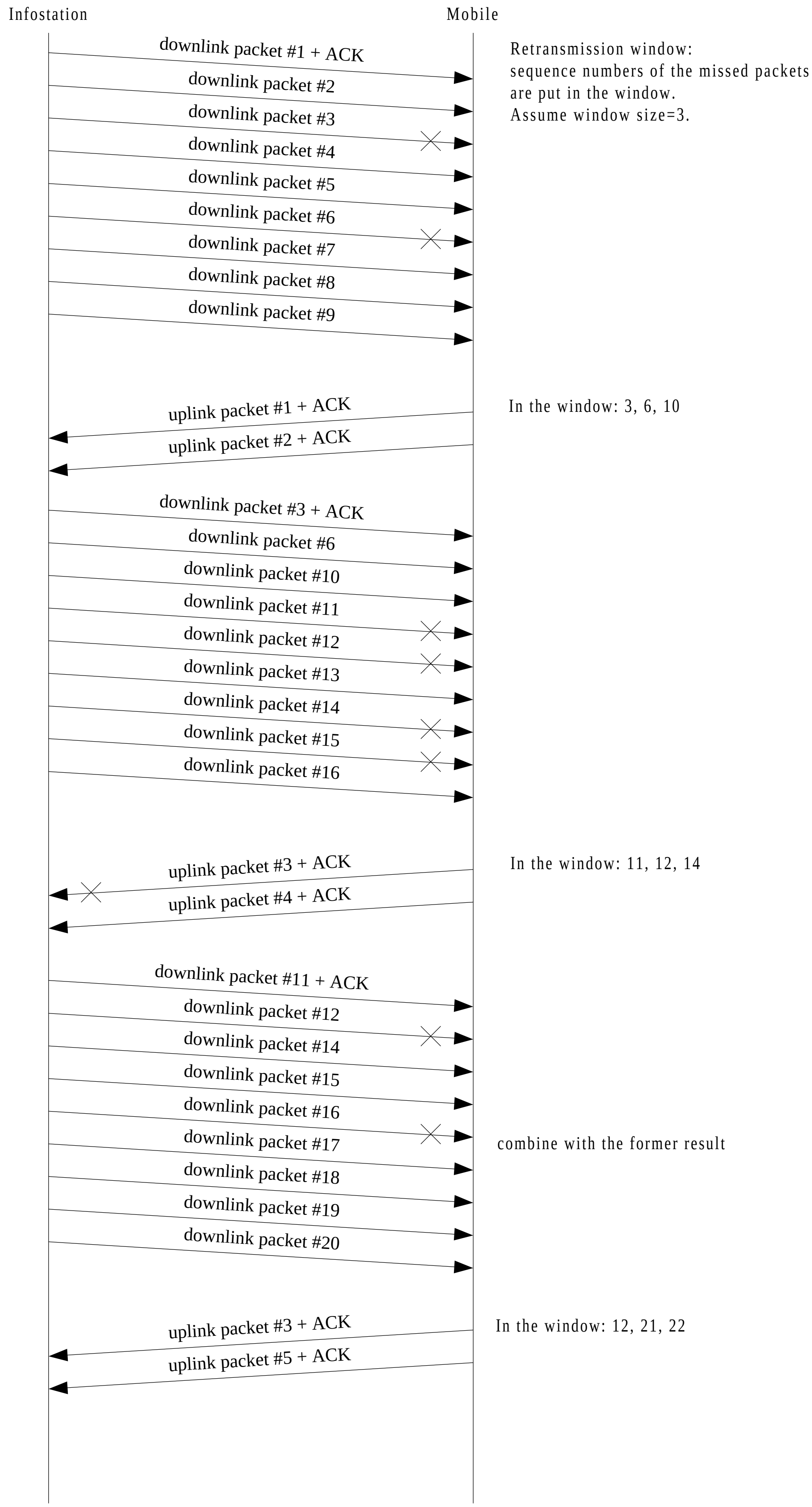
For instance, at R2, counting beacons of R2 and R3 continuously for the most recent 3 beacons.

If 2 out of 3 most recent R3 beacons are heard AND packet error rate for the past 3 frames with current data rate is less than 10%, Then switch to R3; Otherwise if less or equal to 1 out of 3 most recent R2 beacons are heard AND packet error rate of the past 3 frames is higher than 50%. Then switch to R1

Rate Switching Algorithm

3. Coordination of rate switching Request

Upon making the decision to change rate, then the mobile will embed the data rate change request in MAC header in uplink channels of 3 rates within the nearest frame. Upon detecting the request, Infostation embeds Ack in 30 downlink channels in the next frame to make sure the mobile can listen to at least one Ack. If the mobile can listen to at least one Ack, based on the data rate it will change the mobile change receiving data rate in next frame, also it checks the slot allocation table to assign the receiving time slots in the next frame. If the mobile doesn't detect an Ack within the downlink channels, it continues Beacon and PER counting and makes decision as well as requests again.

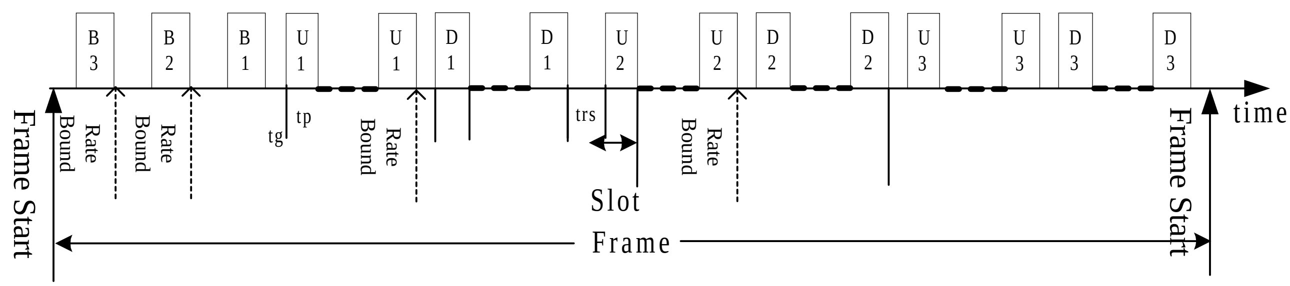


3. Fairness Service and Preemptive Service

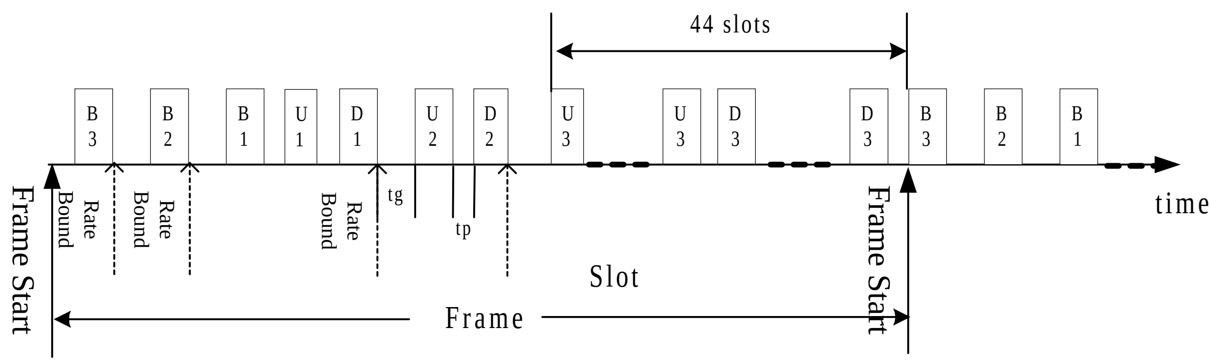
3.1 Definition

- Fairness service (FS): mobile terminals in FS state share the channel resources fairly. Most cases of sit through and walk through require fairness service.
- Preemptive service (PS): the mobile terminal in PS state has the priority to use most of channel resources. Drive through and some cases of walk though and sit through may require PS.

3.2 Fairness Service



3.3 Preemptive Service



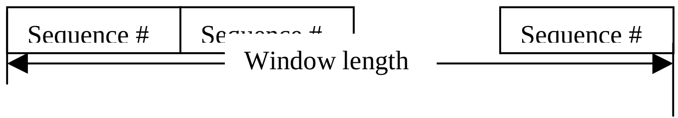
4. Retransmission Scheme

There are generally 3 major ARQ schemes: stop and wait (SW), go back to N (GBN), and selective repeat (SR). Also, one of these basic schemes can be combined with FEC to give rise to a hybrid one, e.g., type I or type II HARQ scheme. Previous researches on ARQ schemes indicated the relationship of efficiency, buffer size, and complexity among SW, GBN, and SR ARQ schemes as follows.

Scheme	Efficiency	Buffer size	Complexity
SW	Low	Small	Low
GBN	Middle	Middle	Middle
SR	High	Large	High

A retransmission scheme is a protocol of data link control layer and is usually designed on the point-to-point basis. In the case of TDMA/TDD, an ACK for a packet transmitted in either direction is only one time per frame. A combination of GBN and SR, PRIME, proposed for AWA (advanced wireless access) system of NTT would be also appropriate for Infostation. The basic idea of PRIME is to use SR within the processing ability of hardware and/or software, e.g., buffer size, and use GBN beyond the ability. To do this, there are some definitions.

A sequence number is defined to be assigned to each packet. A retransmission indication window (RIW), which is one part of an ACK packet, is defined where the sequence numbers of unreceived packets are filled in. A packet is unreceived if the packet is received with uncorrectable error(s) or the packet is not sent. The length of the window is dependent on the buffer size. We describe the scheme with the example (see figure) as follows.



In a TDMA/TDD frame, the infostation sends a number of packets in the downlink direction. These packets, if received successfully, are put in buffers of the receiver. Suppose that the length of RIW is equal to k (=3 in the example). Then the receiver puts k sequence numbers of unreceived packets in the RIW. If the total number of unreceived packets is larger than or equal to the window length (i.e., the number of erroneous packets is lager than or equal to the RIW length), then the sequence numbers should be put into the RIW with the order that a younger number is put in first. Otherwise, the numbers of lost packets are put in followed by the numbers of uncoming packets. For example, in the figure, during the first transmission, packets #3 and #6 are incorrect so the 3 sequence numbers should be #3, #6, and #10. In the second transmission, there are 4 lost packets so the sequence numbers should be #11, #12, and #14. In the last case, the numbers are #12, #21, and #22.

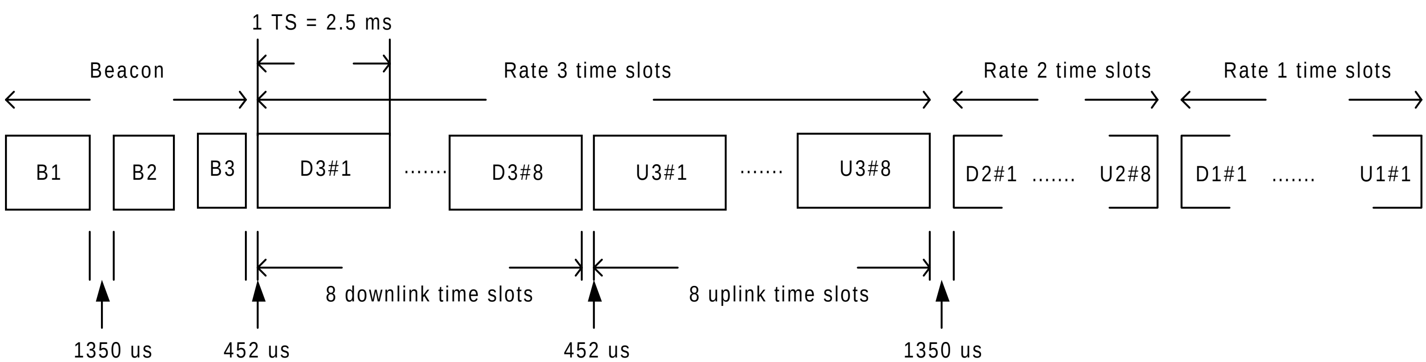
On the other hand, the transmitter retransmits packets with the following procedure. If the last number in RIW is larger than or equal to the last sequence number of the packet just transmitted, then it retransmits all the packets with the sequence number less than the last sequence number just transmitted and follows to transmit new packets. Otherwise, it retransmits all the packets indicated in RIW and the packets followed the last number of packets in RIW and then transmits new packets. From our example, when 3, 6, and 10 are received as RIW at the first time, the transmitter retransmits packets #3 and #6 and transmits new packets beginning from #10. When 11, 12, 14 are received as RIW at the second time, the transmitter retransmits packets #11, #12, #14, #15, #16 and then transmits new packets beginning from #17.

IV Implementation: WINMAC Frame and Packet Formats (for Harris radio)

- Frame format

One MAC frame = 3 beacons + 48 packets, total length = 48*2.048 (packets) + 4*1.305 (guard time) + 46*0.452 (guard time) + 2.688 (beacons) = 127.004 ms

Example: One frame with 24 ups, 24 downs.



- Packet formats

- General MPDU construction: MAC packet header + MAC packet body + MAC CRC

MAC packet header	MAC packet body	MAC CRC (32b)

One MPDU

- General PPDU structure: PHY preamble, header + MPDU + guard time, Length = 2.048 ms + 0.452 ms = 2.5 ms (1 time slot).

PHY preamble and header	MPDU	Guard time

One PPDU

0. MAC packet control (always the first byte in MAC header):

MAC packet type (6b)	Reserved (2b)

Packet control

6 types of packets to be considered:

Packet types	Direction	format in 6 bits
Beacon	Broadcast (Infostation to terminals)	000000
Registration request	Terminal to Infostation	000001
Registration response	Infostation to terminal	000010
Data	Both	000011
Data + Acknowledgement	Both	000100
Acknowledgement	Both	000101
Reservation request	Terminal to Infostation	000110

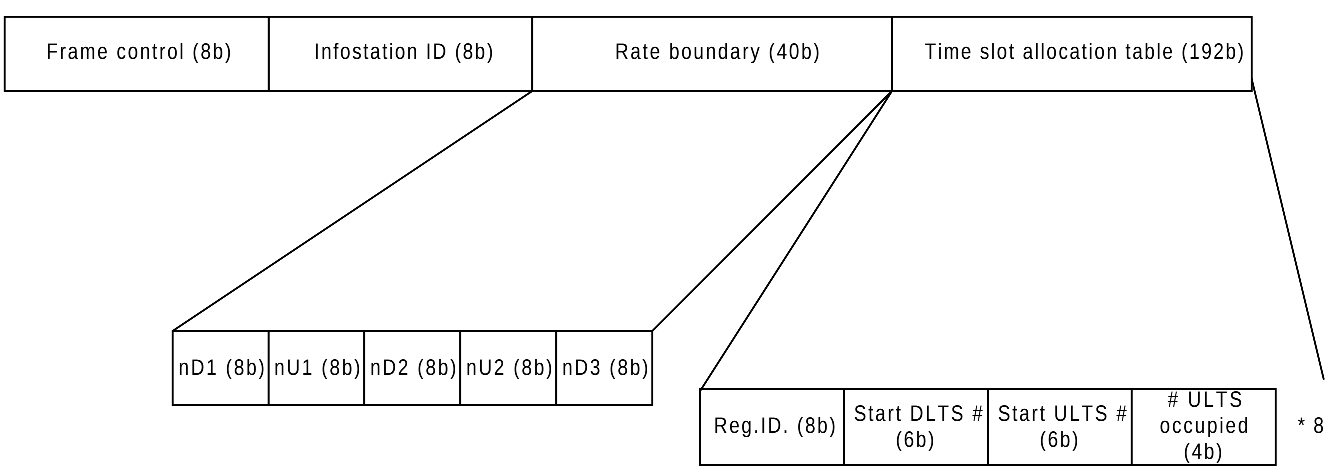
1. Beacon: Header (31) + CRC (4) = 35 bytes

1120 (packet) + 672 (PHY preamble and header) = 1792 us @ 250 kbps

280 + 168 = 448 us @ 1Mbps

140 + 168 = 448 us @ 2Mbps

Beacon



- 40-bit rate boundary: Indicate the boundaries of slots for each bit rate. nDr represents the number of downlink slots at rate 1; nUr represents the number of uplink slots at rate 1, and so on.
- 192-bit time slot allocation table: This is the table containing entries for terminals to learn time slot conditions. Each terminal has 4 entries. The first entry holds a terminal's registration ID (obtained from registration response). The second entry indicates the terminal's first downlink slot number, the third indicates the first uplink slot number. The fourth entry indicates the number of uplink slots the terminal can use. There are space for 8 terminals.

2. Registration request: Header (5) + CRC (4) = 9 bytes

Frame control (8b)	Terminal ID (8b)	Rate select (2b)	App spec (6b)	Reserved (16b)

Registration request

- Terminal ID: represents the terminal's MAC layer ID.
- App spec (Application specification): specifies preemptive mode or fair mode.

3. Registration response: Header (5) + CRC (4) = 9 bytes

Frame control (8b)	Terminal ID (8b)	Registration ID (8b)	Rate select (2b)	Reserved (14b)

Registration response

Registration ID: specifies the terminal's registration is being recognized by the Infostation. It will replace the full-length terminal ID to identify the terminal during the stay of the terminal.

4. Data: Header (5) + Payload (0-461) + CRC (4) = 9 – 470 bytes

Frame control (8b)	Registration ID (8b)	Fragment number (4b)	Sequence number (12b)	Rate select (2b)	Reserved (6b)	MAC payload (0-3866b)

Data

Data + Ack: Data packet header (5) + ACK sequence number (2*N) + Payload (0-?) + CRC (4) = ? bytes

Data + Ack

Data packet header (40b)	ACK sequence (16*N b)	MAC payload (0-?b)

ACK fragment number (4b)	ACK sequence number (12b)	* N

Acknowledgement: Header (5) + CRC (4) = 9 bytes

Frame control (8b)	Registration ID (8b)	Fragment number (4b)	Sequence number (12b)	Rate select (2b)	Reserved (6b)

Acknowledgement

5. Reservation request: Header (5) + CRC (4) = 9 bytes

Frame control (8b)	Registration ID (8b)	Rate select (2b)	App spec (6b)	Reserved (16b)

Reservation request

PHY preamble, header and guard times

- 136 b PHY preamble (120b SYNC + 16b SFD) + 32 PHY header (16b MPDU length + 16b CRC) = 168bits/21bytes.

SYNC (120b)	SFD (16b)	MPDU length (16b	CRC (16b)

PHY preamble + header

  - SYNC: 120 0's.
  - SFD (Start Frame Delimiter): 0x0AF3.
- PHY preamble and PHY header are sent out by DBPSK at the following rates

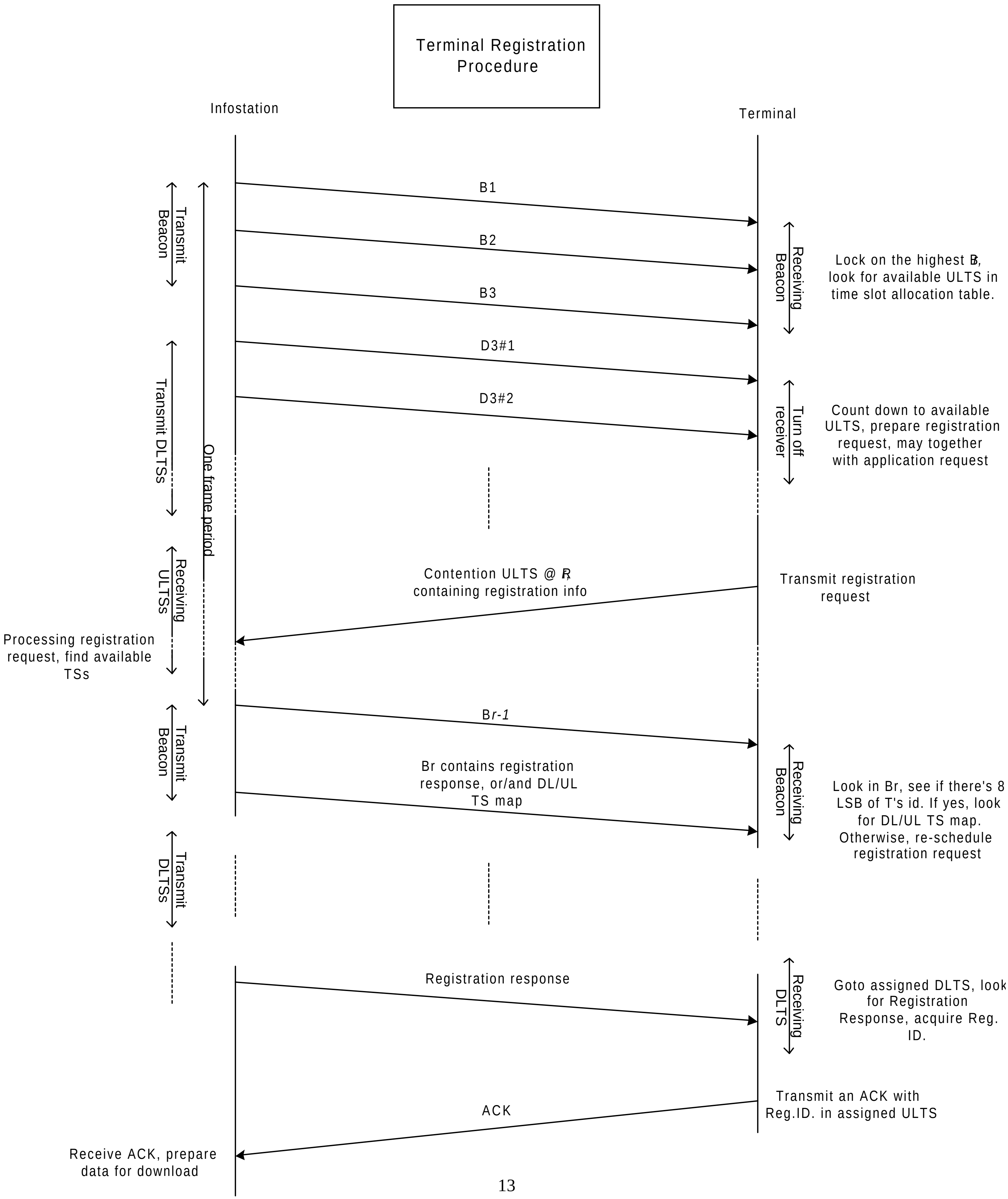
Rate designation	MPDU data rate (bps)	PHY preamble, header rate (bps)	PHY preamble, header time (us)
Low	250K	250K	672
High	1M	1M	168
Hyper	2M	1M	168

- Guard time: 452us (processing delay + rx/tx + propagation delay of r=3km) between TS of the same bit rates; 1350 us between TS of different bit rates.
- Summary Table 1

Rate designation	Max. MPDU time (us)	Max. MPDU length (bits/bytes)
Low	1376	344 /43
High	1880	1880/235
Hyper	1880	3760/470

- Summary Table 2

Frame types	MPDU length in bits/bytes	MPDU length in time (us) @ Low rate	MPDU length in time (us) @ High rate	MPDU length in time (us) @ Hyper rate
Beacon	280/35	1120	280	140
Registration request	72/9	288	72	36
Registration response	72/9	288	72	36
Data	72-3760/9-470	1376 (max.)	1880 (max.)	3760 (max.)
Acknowledgement	72/9	288	72	36


Terminal Registration Procedure
Infostation
Terminal
Transmit Beacon
One frame period
B1
B2
B3
Receiving Beacon
Lock on the highest Bi, look for available ULTS in time slot allocation table.
Transmit DLTSs
D3#1
D3#2
Turn off receiver
Count down to available ULTS, prepare registration request, may together with application request
Receiving ULTSs
Contention ULTS @ Ri containing registration info
Transmit registration request
Processing registration request, find available TSs
Transmit Beacon
Br-1
Br contains registration response, or/and DL/UL TS map
Receiving Beacon
Look in Br, see if there's 8 LSB of T's id. If yes, look for DL/UL TS map. Otherwise, re-schedule registration request
Transmit DLTSs
Registration response
Receiving DLTS
Goto assigned DLTS, look for Registration Response, acquire Reg. ID.
ACK
Transmit an ACK with Reg.ID. in assigned ULTS
Receive ACK, prepare data for download

V Conclusion

In this paper we propose a novel transmission protocol WINMAC for Infostions. A TDMA/TDD channel structure is designed to provide asymmetric uplink and downlink transmission. A TDMA frame includes a number of time slots with the same length in time but different size in bit. In fact, time slots with three transmission rates (i.e., 250Kbps, 1Mbps, and 2Mbps) are supported in a frame. PRMA (Packet Reservation Multiple Access)-TDD is used as the MAC protocol. In fairness service, the channel resource is allocated fairly for the mobile terminals. On the other hand, all the channel resources can be assigned temporarily to a single terminal with a high priority in preemptive service. Since TDMA-TDD is used as the channel structure, a combination of selective repeat and go back to N ARQ scheme with multi-copy technique is designed as the link layer retransmission scheme. Also, a transmission rate switching algorithm is proposed to choose and then switch to the adequate transmission rate.