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A New Efficient Dynamic System Information Scheduling Strategy in TDD-LTE

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Abstract

The TDD-LTE system information which is also necessary to communicate each other well is a kind of important message between user equipment (UE) and eNodeB. Some important parameters are provided by system information to enable the UE to camp on a cell normally and access to common channel. The system information, of course, can provide the mobility management for UE in idle mode. On the base station side, there are two kinds of scheduling methods of in the TDD-LTE system, and they are fixed scheduling and dynamic scheduling. The MasterInformationBlock (MIB) and the SystemInformationBlockType1 use the fixed scheduling, while the dynamic scheduling is applied to other SystemInformationBlocks (SIB2~SIB13); and these system information are transmitted on the Downlink Shared Channel (DL-SCH). In consideration of using the radio resources reasonably and not affecting other downlink transmitted data, we proposed a dynamic scheduling strategy of system information based on the base station side.

Keywords: *TDD-LTE, system information SI, dynamic scheduling, downlink shared channel (DL-SCH)*

1. Introduction

With the rapid development of the society, Time-Division Long-Term Evolution (TD-LTE) also referred to as Long-Term Evolution Time-Division Duplex (LTE TDD) is a 4G mobile telecommunications technology and standard. Now the TDD-LTE is launching commercial trials. The TDD-LTE technology has many outstanding features [1-3]:

1) Flexible support of six different bandwidths for 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, 20MHz.

2) OFDMA for the downlink, the downlink peak rates of 100Mbits/s, meeting the demand of high-speed transmission of data.

3) SC-FDMA for the uplink to conserve power, guaranteeing better system performance as well as reducing the Peak to Average Power Ratio (PAPR), lowering the transmitted power of UE with the uplink peak rates of 50Mbits/s.

4) Applying smart antennas to lowering inter-cell interference and enhancing the Quality of Service(QOS) for the cell-edge users.

5) Scheduling the radio resource in the time domain, space domain and frequency domain with ideal throughput and Quality of Service (QOS).

System information is a type of cell-level message which is common for all the UEs in this cell. The purpose of system information is to enable the UEs to access cells providing service, and to provide UEs to access common channel of radio access network and guarantee the mobility management in idle mode. Therefore, the communication between UEs and eNodeB will be unsuccessful when the system information works abnormally. At present, the system information scheduling has been drawn much attention. Thus these research works are the popular theme of the TDD-LTE and also affect the large-scale TDD-LTE field trial in future [4-5].

Nowadays the research on downlink radio resource allocation and scheduling algorithm are mainly focusing on the performance, for the whole LTE system, caused by the algorithm. A novel cross-layer scheduling algorithm based on traffic load of different users was proposed in[6] that aims to minimize the problem of the overall average packet delay. The resource blocks and a modulation and coding scheme are taken into account to achieve its goal. In [7] this

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contribution analyses the problem of the provision of Quality of Service (QoS) to users of LTE networks depends to a large degree on the choice of an proper scheduling algorithm. At the same time, the relationship between scheduling policies, offered levels of QoS (expressed in terms of guaranteed bit rates) and control channels capacity are described in this contribution. A scheduling algorithm, from the fairness point of view, was introduced in [8] which aims to improve the performance of the cell-edge users.

2. System Information

2.1. Procedure of Scheduling

The system information (SI) is a kind of key message for the LTE system and is broadcasted periodically in the cell. When the eNodeB begins to work in normal condition, it will create cells firstly, configure related parameters, active cells , active the broadcast and then provide the Non-Access Stratum (NAS) messages and Access Stratum (AS) messages which are acquired by the UEs when the UEs in RRC_IDLE and in RRC_CONNECTED. When the UE is from switching on to camping on a cell [9-10], from the UEs point of view, the following steps will be done such as: cell search, recognizing and acquiring cell downlink synchronization, acquiring the system broadcast message and then followed by interaction about the RRC signaling related. From the view of signaling interaction between UE and eNodeB, the system information acquired accurately by UE must be completed before communicating each other normally.

2.2. Classification of System Information

The system information for LTE system broadcasted on the LTE-Uu interface could be divided into three classes:

1) MIB (MasterInformationBlock): the MIB includes a limited number of most essential and most frequently transmitted parameters that are needed to acquire other information from the cell such as the downlink bandwidth (dl- bandwidth) of the cell, Physical Hybrid ARQ Indicator Channel (PHICH) and the 8 most significant bits of the System Frame Number (SFN).

2) *SystemInformationBlockType1* (SIB1): some very important parameters are mainly included in SIB1 such as cell access related, the configuration about scheduling information of SI refered to the SI-window length and the transmission periodicity, and the systemInfoValueTag which indicates whether the system information has been changed or not.

3) The rest of other SIBs: the rest of SIBs include the range from SIB2 to SIBn($2 \le n \le 13$). These SIBs mainly include the parameters which control the cell reselection and handover about intra-frequency and inter-frequency in the cell.

In terms of the description from 3GPP Std TS 36.331 [10] (E—UTRA, Radio Resource Control Protocol Specification, Release 9), the system information can be scheduled in different ways when the LTE eNodeB broadcasts the system information on the LTE-Uu interface.

There are fixed scheduling method and dynamic scheduling method for the system information.

1) Fixed scheduling:

The MIB uses a fixed scheduling with a periodicity of 40 ms and repetitions made within 40 ms. The first transmission of the MIB is scheduled in subframe #0 of radio frames for which the SFN mod 4 = 0, and repetitions are scheduled in subframe #0 of all other radio frames. The MIB is employing a static schedule in the time domain and in the frequency domain, and is transmitted on the PBCH. In time domain, the SystemInformationBlockType1(SIB1) uses a fixed scheduling with a periodicity of 80 ms and repetitions made within 80 ms. The first transmission of SystemInformationBlockType1 is scheduled in subframe #5 of radio frames for which the SFN mod 8 = 0, and repetitions are scheduled in subframe #5 of all other radio frames for which SFN mod 2 = 0 [10-11].

2) Dynamic scheduling:

Other SIBn($2 \le n \le 13$) uses a dynamic scheduling. According to the 3GPP TS 36.331, the dynamic scheduling should comply with some restrictions as follow:

a) The unit of dynamic scheduling is a system information (SI), which means one or more SIB could be mapped to a SI message.

b) Each SIB is contained only in a single SI message, only SIBs having the same scheduling requirement (periodicity) can be mapped to the same SI message.

c) *SystemInformationBlockType2* (SIB2) is always mapped to the SI message that corresponds to the first entry in the list of SI messages (SI-1) in schedulingInfoList. Thus, the SIB2 must be contained in the first SI message (SI-1) at any time.

d) There may be multiple SI messages transmitted with the same periodicity. The SI messages are scheduled and transmitted periodically in the SI-window which is configured flexibly in the SIB1 and is common for all SI messages.

e) There are three kinds of subframes which are not used to schedules the SI messages. They are Multicast Broadcast Single Frequency Network (MBSFN) subframe, uplink subframes in TDD as well as subframe #5 of radio frames for which the SFN mod 2 = 0.

f) SIB1 and all SI messages are mapped to BCCH and transmitted on Downlink Shared Channel(DL-SCH).

3. Strategy of SI Dynamic Scheduling

For TDD-LTE systems, the transmitted data of uplink and downlink is arranged to different time-slots on the same frequency band and sent them by discontinuous way. In the light of different uplink-downlink configurations in one radio frame of TDD, the percentage of downlink subframe in all subframes is also different. Due to the SI messages transmitted on the DL-SCH, it denotes that the transmitted SI messages share the downlink radio resource with other downlink data. Either the radio resource to be wasted or affecting the transmission of downlink packet data, if the SI dynamic scheduling is not arranged reasonably. Therefore, the unreasonable SI dynamic scheduling will also degrade the efficiency of UE acquiring the system information, and affect heavily the overall performance of LTE system. In view of using the radio resources reasonably, we proposed a efficient dynamic scheduling strategy of system information based on the base station side.

The flow chart of our proposed dynamic scheduling strategy based on downlink radio resource is illustrated in Figure 1.

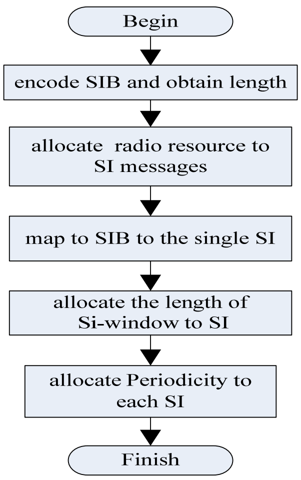

Figure 1. Illustration of the Flow Chart for our Proposed Dynamic Scheduling Strategy based on Downlink Radio Resource

The strategy mainly includes the following steps: 1) encode each SIB respectively and obtain the corresponding encoded length, 2) calculate the downlink radio resource which can be allocated to SI dynamic scheduling, 3) determine each SI-n($n \geq 1$) composed of which SIBs, 4) allocate the length of SI-widow to each SI, 5) allocate periodicity respectively to each SI.

3.1. Encoding SIB

According to the description of SIBn($2 \le n \le 13$) for LTE protocols, each parameter of SIBn ($2 \le n \le 13$) is properly assigned to a numerical value, and then encode the corresponding SIB to obtain the encoded length (denoted as $sibn\text{-}len$) [12-13].

3.2. Calculating the Quantity of Available Radio Resource

While doing the research on downlink radio resource that can be allocated to SI dynamic scheduling, we find that some following factors affect the quantity of available radio resource [14-16].

1) The value of cyclic prefix configured by LTE system:

If the value of cyclic prefix is configured as normal cyclic prefix, then the resource block (RB) of one time-slot corresponds to seven OFDM symbols in the time domain. If the value of cyclic prefix is configured as extended cyclic prefix, then the resource block (RB) of one time-slot corresponds to six OFDM symbols in the time domain [17-18]. We use the N_{CP} as the symbol for the value of cyclic prefix.

2) Support for the bandwidth of LTE system:

There are six different cell bandwidths supported by LTE system. Under different bandwidth, the number of RB is also different according to corresponding bandwidth in one time-slot in the frequency domain. The relationship between different downlink bandwidth configurations and the number of RB is given in the Table 1. We use the N_{RB}^{dl} as the symbol for the number of RB.

Table 1. Relationship between Channel Bandwidth and the Number of RB

Channel Bandwidth[MHz]	1.4	3	5	10	15	20
The Number of RB: N_{RB}^{dl}	6	15	25	50	75	100

3) Support for the value of spectral efficiency:

Spectral efficiency indicates that a modulation symbol can carry, on average, the number of bits before encoding. The number of bits which a modulation symbol can carry is different with different spectral efficiencies. We use the N_{eff} to denote the symbol for the spectral efficiency.

4) Limited RB:

Due to the transmission of SI messages sharing the DL-SCH with other downlink data, thus the quantity of available RB for scheduling SI is limited in consideration of downlink subframe in TDD-LTE system [18-19]. In view of overall performance of TDD-LTE system, we define a percentage (referred to as N_{ratio}) as follow: the percent of the radio resource occupied by transmission of SI messages in the total downlink radio resource.

Therefore, the total of downlink RB(RB_{total}) in a downlink subframe is:

$$RB_{total} = N_{RB}^{dl} \times 2 \quad (1)$$

The number of all resource elements (RE_{total}) in a downlink subframe are:

$$RE_{total} = RB_{total} \times 12 \times N_{CP} \quad (2)$$

Where 12 denotes a subframe corresponds to 12 subcarriers in the frequency domain. The total resource elements (RE_{enable}) which are available to transmit downlink data in a downlink subframe are:

$$RE_{enable} = RE_{total} - N_{RB}^{dl} \times 12 \times 3 \quad (3)$$

Where, 3 indicates that the first three OFDM symbols in a downlink subframe. The three OFDM symbols are unable to transmit the SI messages and other data. Therefore, the total bits that could transmit downlink data in a downlink subframe is:

$$Bit_{enable} = RE_{enable} \times N_{eff} \tag{4}$$

From the Equation (1) to (4), we could find that the total number of available resource to transmit SI messages in a downlink subframe is:

$$N_{total}^{resource} = N_{ratio} \times N_{RB}^{dl} \times N_{eff} \times 12 \times (2N_{cp} - 3) \tag{5}$$

3.3. Mapping SIB to SI

From Equation (5), we know that the radio resource $N_{total}^{resource}$ used to transmit the system information can specify each mapping of SIB to SI:

$$0 < SibSumLen(sib1 - len + sib2 - len + \cdots + sibn - len) < N_{total}^{resource} \tag{6}$$

Where, function $SibSumLen()$ denotes the accumulated sum of SIBn ($2 \le n \le 13$). In this paper, considering the properties of the radio resource and the reception efficiency of the terminal UE, we shall specify the radio resource assigned to the dynamic scheduling of system information. The procedure of the flow chart is illustrated in Figure 2. In general, with regard to the design of the mapping of SIB to SI, we must follow the rules:

1) With a minimum number of SI;

2) System information block SIBm should be mapped to SI before the SIBn (m<n), say, SIB-m must be scheduled and transmitted more in advance than the SIBn.

In Figure 2, the retained set {SI-n} represents the stored set of SIB for the corresponding SI-n after being determined. The excluded set {SIB-n} denotes the remaining set of SIB for each corresponding SI-n. And the {SIB-n} will be used to determine the next SI. It should be noted that all SIB included in the {SI-n} and {SIB-n} are arranged in order of increasing serial numbers. The following procedures apply:

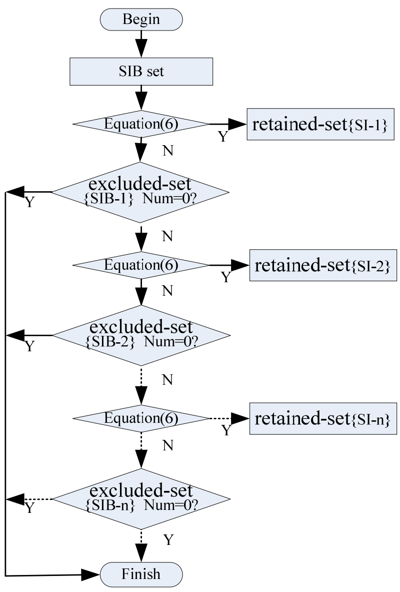

Figure 2. Illustration of the Flow Chart for Specifying the Dynamic Scheduling Radio Resource Assigned to the System

Where the Num, in Figure 2, denotes that the number of SIB included in the excluded set{SIB-n}.

1) Determination the composition of SIB in the SI-1:

According to the protocol, the SIB-2 must be included in SI-1. When sib2-len doesn't fulfill the condition of Equation (6), the amplitude of the N_{ratio} and N_{eff} allocated by the LET system is not reasonable. In this case, the system should send out a warning message of "unable to schedule" and instruct the base station to reconfigure the reasonable values of N_{ratio} and N_{eff} .

If sib2-len satisfies the Equation (6), we will add SIB-2 to the retained set {SI-1}. Then continue to determine whether or not sib3-len satisfies the Equation (6). If yes, then SIB-3 is added to the retained set {SI-1}; If not, SIB-3 is stored to the excluded set {SIB-1} and remove the sib3-len from the function SibSumLem(). For other sibn-len ($4 \le n \le 13$), we can follow the same procedure as done for sib3-len. If sibn-len satisfy the Equation (6), add the SIB-n to the {SI-1}, otherwise to the {SIB-1} and remove sibn-len from the function SibSumLem(). Until all sibn-len have been performed, then we could know that the retained set {SI-1} just consist of all SIBs.

If the number of SIB included in the excluded set {SIB-1} is zero, it means that there is just one SI and then the combination of mapping of SIBs to SI-1 is completed, otherwise, we should turn to the combination of mapping of SIBs to SI-2.

2) Determination the composition of SIB in the SI-2:

After specifying the composition of SIB in the SI-1, we add the corresponding length of the first SIB-m in {SIB-1} to Equation (6) and determine whether or not sibm-len fulfills the condition. If not, store the SIBm in the excluded set {SIB-2}, then add in turn the corresponding sib-len of each SIB in {SIB-1} to the Equation (6). According to the rules of combination of SI-1, we can store the SIB which are fulfilled the Equation (6) in the retained set {SI-2}, otherwise, store it in excluded set {SIB-2}. If all SIB of {SIB-1} can not satisfy the Equation (6), the system should send out the warning message of "unable to schedule" and instruct the base station to reconfigure the reasonable N_{ratio} and N_{eff} values.

If the above step has been completed, then the retained set {SI-2} consists of all SIBs included in {SI-2}.

If the corresponding number of SIB in the excluded set {SIB-2} is zero, the whole combination of mapping of SIB is completed; otherwise, continue to perform the next combination of judgment of SI.

3) Determination the composition of SIB in the SI-n ($n \ge 3$):

Following the same rules of combination of SI-1 and SI-2, we can repeat the procedures to determine what composition of SIB included in each SI-n. After that, we can complete the whole combination of mapping of SIB to SI.

3.4. Determination the Length of SI-window for SI

The SI messages are transmitted within periodically occurring time domain windows (referred to as SI-window) using dynamic scheduling, and each SI message is associated with a SI-window. The SI message can be transmitted a number of times in any subframe other than MBSFN subframes, uplink subframes in TDD, and subframe #5 of radio frames for which SFN mod 2 = 0. Considering the restrictions of subframe as above, these restrictions also affect the length of the SI-window. Therefore, while we are having a research on the radio frame of TDD, the minimum length of the SI-window ($SI-WindowLen$) is obtained in terms of different uplink-downlink configurations(N_{dl}). The relationship between minimum length of the SI-window and the corresponding N_{dl} is given in Table 2. According to a certain N_{dl}, in Table 2, the length of each SI -window should be greater than the minimum length of the SI-window corresponding to N_{dl} when we allocate the length of SI-window to each SI.

Table 2. Minimum Length of the SI-window and Corresponding N_{dl}

N_{dl}	0	1	2	3	4	5	6
Minimum length of SI-window(ms)	10	5	5	5	5	5	5

3.5. Allocation Scheduling Periodicity to SI

While allocating periodicity to each SI respectively, in terms of the description from LTE protocols, we must make sure that the each SI-window will not to be overlapped. The LTE protocols specify seven periodicities for SI. These periodicities are as follow: 8rf, 16rf, 32rf, 64rf, 128rf, 256rf, 512rf. Where rf means the number of radio frame. To ensure each SI-window will not to be overlapped, the minimum periodicity of SI should be defined as follow:

$$Min(SI-Periodicity_i) >= Sum(SI-WindowLen_j)/10 \quad (7)$$

Where:

(1) The function $Min()$ is to obtain the minimum periodicity of SI according to the description from LTE protocols.

(2) The function $Sum()$ is to obtain the sum of all length of the SI-window.

(3) The i ($i \geq 1$) and j ($j \geq 1$) are the sequence number of SI.

(4) The $SI-WindowLen_j$ indicates the length of the SI-window for the SI-j, and the $SI-Periodicity_i$ denotes the periodicity of the SI-i.

According to the Equation (7) and in consideration of the efficiency of UE acquiring and analyzing the system broadcast information, a principle which is how to allocate dynamic scheduling periodicity to each SI is described as:

$$Ceiling(Sum(SI-WindowLen_j)/10)=Min(SI-Periodicity_i) \quad (8)$$

$$SI\text{-}Periodicity_1 = Ceiling(Sum(SI-WindowLen_j)/10) \quad (9)$$

$$SI\text{-}Periodicity_i < SI\text{-}Periodicity_j \quad (1 \leq i < j) \quad (10)$$

Where:

(1) The $Ceiling()$ is a function which maps a real number to the smallest following integer.

(2) We use $SI\text{-}Periodicity_1$ as the periodicity of SI-1 in the light of our proposed strategy.

(3) To choose the first value which is bigger than the $SI\text{-}Periodicity_1$ in the seven periodicities provided by LTE protocols as the periodicity of SI-2($SI\text{-}Periodicity_2$); then, bigger than the $SI\text{-}Periodicity_2$ as the periodicity of SI-3($SI\text{-}Periodicity_3$), increase all periodicities of SI according to same rule.

4. Simulation and Results

We firstly use computer language to describe our proposed strategy model with using Femto [20] and TM500 which is a simulator of mobile terminal as the experimental equipments during the experiment. At the same time, the Femto currently supports MIB and part of other SIBs such as SIB1, SIB2, SIB3, SIB4, SIB5. Then the real-time communication is conducting between Femto and TM500 to test the feasibility of our proposed strategy model.

1) Obtaining the encoded length of each SIB in terms of our strategy model. The encoded length is shown in Table 3.

Table 3. SIB and Encoded Length of SIB

SIB type	SIB2	SIB3	SIB4	SIB5
encoded length [bit]	228	86	500	4154

2) According to the parameters configured by the whole system of Femto, we can obtain $N_{total}^{resource}$ = 4656 bit.

3) Through analyzing our strategy model and the two steps as above, then the expected results could be given as follow: 1) there are two SIs in this experiment; 2) the SIB2, SIB3 and SIB4 are mapped to the SI-1; 3) the SI-2 only consists of SIB5.

4) We extract the signaling window (seeing from Figure 3 to Figure 7) of TM500, and the signaling window has been recorded what happened during the real-time communication between them. Therefore, if we open the third signaling, systemInformation (SI-1), marked with blue color in Figure 3, then we can learn that which SIBs are mapped to SI-1. From the Figure 3 to Figure 5, we could found that the SI-1 is actually composed of SIB2, SIB3 and SIB4.

5) Learning that the SIB5 is contained in the SI-2, while opening the fourth signaling, systemInformation (SI-2), marked with blue color in Figure 6.

6) The complete procedure of signaling is shown in Figure 7. These signalings shows what happened on the LTE-Uu interface when the TM500 communicates normally with the Femto. these signalings include as follow: UE acquiring system broadcast information (MIB, SI-1, SI-2) and analyzing system information; RRCconnectionSetUp; securityModeCommand; ueCapabilityInformation; until the SRB2 established on the LTE-Uu interface. From the signaling in Figure 7, the UE successfully attach to the cell which is created by the Femto.

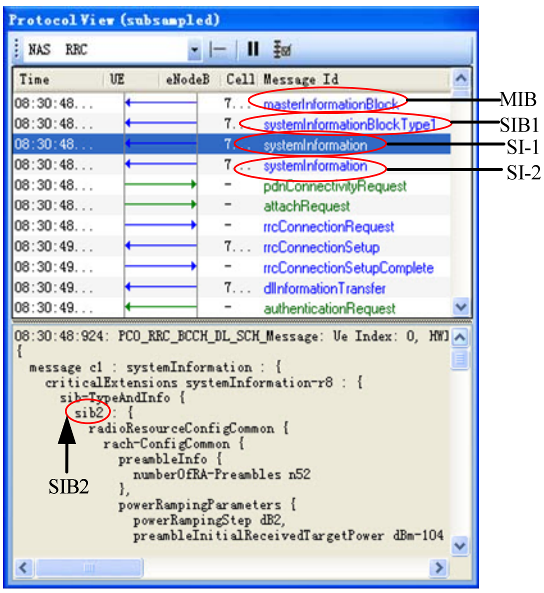

Figure 3. The SIB2 in SI-1

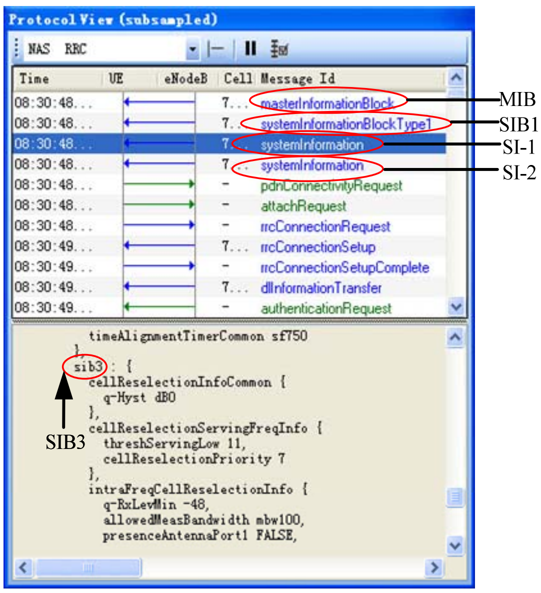

Figure 4. The SIB3 in SI-1

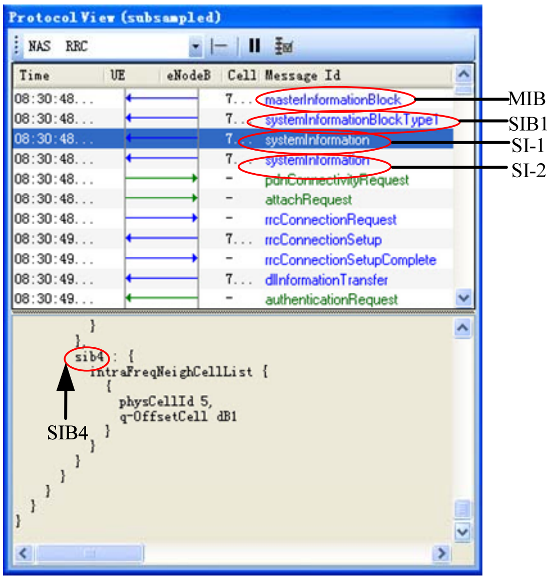

Figure 5. The SIB4 in SI-1

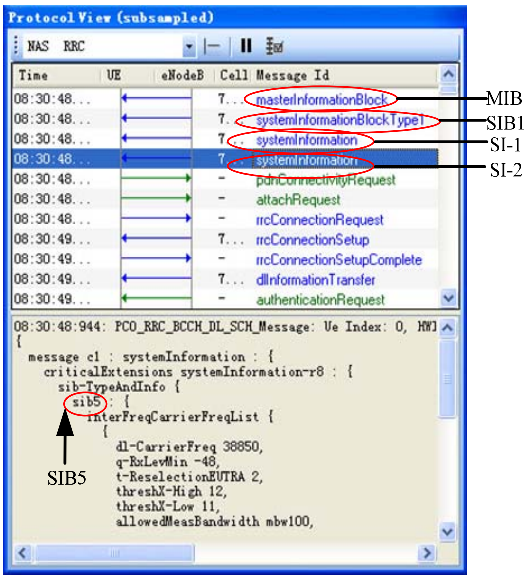

Figure 6. The SIB5 in SI-2

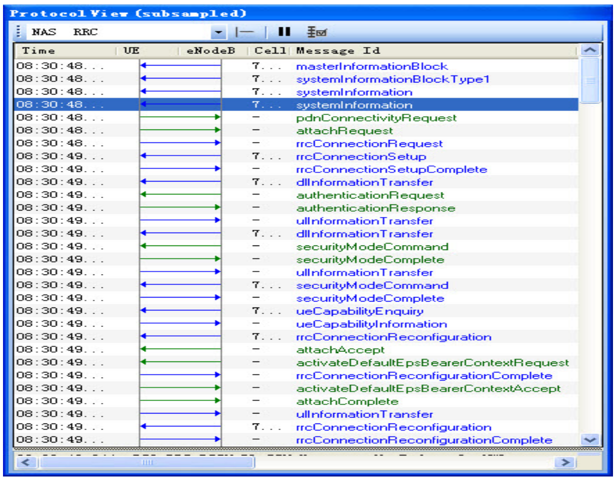

Figure 7. The Procedure of Signaling on LTE-Uu Interface

On the basis of analysis as described above, the experiment result that is from the real-time communication between experimental equipment is in conformity with the expected result which is provided by our proposed strategy model. Therefore, the experiment result indicates that our proposed model is feasible and practical.

5. Conclusion

In this paper, the mechanism of transmission for system broadcast information of TDD-LTE is studied. We have introduced a practical SI dynamic scheduling strategy model for LTE wireless networks. This proposed model is in consideration of downlink radio resource and efficiency of UE acquiring the broadcast information. Our strategy model has been successfully and efficiently solved the problem that how to map the SIB to SI and how to schedule SI. With the large-scale TDD-LTE commercial trial conducting in the world, our strategy model will be practical.

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