Performance Evaluation of the UTRAN Transport Network for the High Speed Downlink Packet Access

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***Abstract*— This paper examines the impact of the High Speed Downlink Packet Access (HSDPA) traffic on the UTRAN I_{ub} transport link. In this paper, we compare the performance of an IP based I_{ub} link with the existing AAL2/ATM based I_{ub} link. An OPNET based simulation model has been developed to study performance both I_{ub} links. Simulation results show the performance of an IP based UTRAN is superior to that an ATM UTRAN for supporting sustainable high data rate on the air interface.**

Keywords- UTRAN, ATM, IP, HSDPA, HSPA, LTE.

I. Introduction

The WCDMA based UMTS radio network standard was developed with an aim to support multimedia traffic. With the successful deployment of 3G mobile radio networks the worldwide subscription level has reached to 44 million [1]. At the same time mobile data revenue hit US$100 billion in 2005 and continues to grow in 2006. To serve diverse type of mobile users it is necessary for current 3G mobile systems continue to evolve as planned under the Long Term Evolution (LTE) plan. The 3GPP is in the process of defining the LTE plan for 3G radio access [1]. As one of the initial steps of evolution the 3GPP has introduced the High Speed Packet Access (HSPA) standard. The HSPA standard is consists of a downlink known as the HSDPA (High Speed Downlink Packet Access) and an uplink which is known as the HSUPA (High Speed Uplink Packet Access) is based on the enhanced DCH (Dedicated Channel) structure[2]. The HSDPA architecture was introduced in 3GPP release 5. The HSDPA channel uses a short 2ms transmission time interval (TTI), and uses variable coding and modulation techniques to achieve high data rate. In addition to above techniques the Node B based fast scheduling and fast physical layer hybrid automatic repeat request (H-ARQ) techniques are used in the HSDPA standard.

Considering current and future developments it is important that RAN (Radio Access Network) architecture is optimized to support high data rate air interfaces with dynamic heterogeneous traffic. The performance of the I_{ub} link is one of the important issues for a radio access network (RAN) to support real time and non-real time traffic with different QoS (Quality of Service) requirements. The end-to-end QoS of a data connection will be affected by individual link qualities. In the recently published 3GPP technical report the E-UTRAN architecture specifies the UE (User Equipment) to RNC (Radio Network Controller) transmission delay should be lower than 10 ms [3]. For a HSDPA data connection the QoS of an I_{ub} link will be significantly affected by radio link characteristics hence, some form of radio link based scheduling needs to be used in the UTRAN. A HSDPA scheduler allocates the channel to a single user for a TTI period of 2 ms. In this work we are considering the downlink connection from a RNC to an UE to support peak transmission rate. Here we use both the ATM (Asynchronous Transmission Mode) and IP (Internet Protocol) based I_{ub} links to measure the delay profile and buffer requirements of a Node-B and a RNC (Radio Network Controller) to support peak HSDPA data rates. In any network the radio channel condition will be variable and hence, it is necessary for an I_{ub} link scheduler to match the radio channel characteristics to support peak transmission rate between a Node-B and an UE. In the release 99 of 3GPP, the AAL2/ATM transport technology was chosen to transmit multimedia traffic on the I_{ub} interface. In the 3GPP release 5, an IP-based transport technology has been identified as the appropriate transmission technology for the next generation system. In the release 5 three user plane solutions are proposed, those includes the CIP (Composite IP), LIPE (Lightweight IP Encapsulation) and PPP-MUX (Point-to-Point Protocol Multiplexing) solutions. In this paper, a CIP based solution is studied and compared with an AAL2/ATM based link.

Reviewing the literature in the area of UTRAN we found several works have concentrated on some aspects of RAN for ATM and IP based transmission schemes. The MWIF (Mobile Wireless Internet Forum) [4] has initially the studied performance comparison of ATM and IP based transport networks for DCH traffic. Some important IP network related technical issues such as QoS, link efficiency, size of IP packets, routing, and security were considered. Chang Yong Jung et. al. [5] evaluated the performance of ATM based and IP based transmission schemes with various types of input traffic in terms of link efficiency and average link transmission delay. However, both the works assumed that the RAN traffic is transmitted via the DCH channel which generates less bursty traffic on the I_{ub} link than the HSDPA traffic. Also, these works didn't consider the effect of radio channel conditions on the traffic scheduling techniques (UP or DOWN link) in the

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UTRAN. Our simulation shows that because of different packet scheduling schemes used on DCH and HSDPA channels the offered traffic characteristics at the node-B are different and introduces different delay profiles which could affect network designs.

The paper is organized as follows. Section II briefly describes the UTRAN protocol structure used for the HSDPA connection. Section III describes AAL2/ATM and IP connection structures for the UTRAN to transmit the HS-DSCH FP (High Speed Dedicated Shared Channel Frame Protocol) Frames. Section IV describes traffic and simulation models. The section V presents some initial simulation results and discusses implications of simulation results on the HSDPA link design. Conclusions are presented in the section VI.

II. UTRAN Protocol Structure

The HSDPA protocol structure is shown in Fig. 1. The HS-DSCH (High Speed Dedicated Shared Channel) is the transport channel that carries the actual user HSDPA data. The HS-DSCH FP handles the data transport between a RNC and a Node B. For a HSDPA connection data received from a core network is packed into HS-DSCH frames and transmitted on the I_{ub} link using either the ATM or the IP layers. The MAC-hs layer implements the hybrid ARQ and scheduling functionalities in a Node B [6].

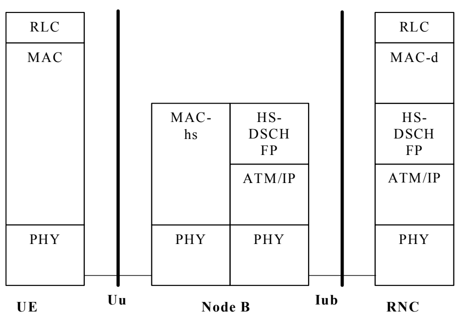

Figure 1. Protocol Architecture of HSDPA

In the HSDPA architecture a buffer is used in the node-B. The buffer along with a scheduler which shares the transmission resources enables a higher peak rate for a radio link than the average rate on $I_{ub}/I_{u\text{-}ps}$ links [2]. With a buffer in a Node-B it is necessary to use a flow control on the I_{ub} link to avoid buffer overflow or buffer starvation. Under a good radio channel condition a HSDPA link may not be able to transmit at its peak rate because of the buffer starvation. Unless a large buffer is maintained at a node-B or an I_{ub} is designed appropriately to support fast data transfer between a node-B and RNC the buffer starvation problem could reduce the throughput of a HSDPA connection. Hence, it is necessary to allocate an I_{ub} link capacity according to the transmission channel condition as well as the buffer occupancy level at the node-B. Several new functionalities have been added at node-B and at RNC to support the HSDPA operation [2]. Some of the main functionalities of the RNC are the HSDPA I_{ub} traffic management, HSDPA radio resource and mobility management, and handling of large data volumes. Main layer two functionalities of the Node-B for a HSDPA connection are data buffering, ARQ handling, flow control and downlink scheduling. Considering the requirements of HSDPA connections it is now apparent that the I_{ub} link plays an important role in the overall QoS of a connection. Similarly the same link plays an important role for HSUPA connections. In this paper we are not considering the HSUPA issues. As mentioned earlier that in this paper we comparing the delay profiles of current generation ATM based RAN with an IP based RAN to study the I_{ub} traffic management issues. If the frame delay of an I_{ub} link is high then it may not be possible to sustain a peak transmission rate because the I_{ub} link will not be able to adapt its transmission rate with rapidly varying channel conditions, consequently reducing the efficiency of the HSDPA air interface. Data transmission delay between the RNC and Node-B is controlled by the frame transmission protocols. In the following section we describe data transmission formats of ATM and IP connections.

III. AAL2/ATM and IP Connection Structure

In this work we consider the HSDPA traffic transmission between the RNC and the node-B. The RNC will receive data traffic via the $I_{u\text{-}ps}$ interface for forward transmission. Fig. 1 shows the I_{ub} protocol stack which receives data traffic from the $I_{u\text{-}ps}$ layers then adds RLC, MAC-d and HS-DSCH FP headers before delivering the PDU (Protocol Data Unit) to the layer 2. In the FDD (Frequency Division Duplex) mode a maximum of 70 MAC-d PDU can be transmitted in a single TTI. The HS-DSCH layer packs multiple MAC-d PDUs to transmit in a single HS-DSCH FP frame. Transmission delay of the HS-DSCH frame will depend on the lower layer frame/cell transmission techniques. In following sections we briefly describe the HS-DSCH FP frame mapping procedures.

A. ATM based I_{ub} Link

In the release 5 of 3GPP both AAL2/ATM, AAL5/ATM and IP based UTRAN are supported. The AAL2 (ATM Adaptation Layer 2) supports for bandwidth-efficient transmission of low-rate, short, and variable length packets generated by delay sensitive applications. The AAL2 link can also be configured to support non-real time traffic in the non-assured mode. The high layer data unit exceeding 45 bytes (or 64 bytes) is segmented into maximum length of 45 bytes (or 64 bytes) packet and 3 bytes header are added to form a CPS-Packet. The CPS-Packet header includes Channel Identifier (CID 8 bits), Length Indicator (LI 6 bits), User-to-User Indication (UUI 5 bits) and Header Error Control (HEC 5 bits). Reassembly service is provided on the reverse link. Multiplexing in the AAL2 occurs in the Common Part Sub-layer (CPS). CPS-Packets are mapped into the CPS-PDU payload. The CPS-PDU consists of one octet start field (STF) and a 47-octet payload. The 48-octet CPS-PDU becomes the ATM-SDU as shown in Fig. 2 [7]. For data connections AAL5 is proposed which forgoes the multiplexing capabilities but support stream modes by including signaling bits. However, the AAL2 and AAL5 use the same underlying ATM layer which transmits a short 48 bytes cell.

B. IP based I_{ub} Link

To support efficient usage of the I_{ub} link using the IP solution the CIP (Composite IP) option can be used. The CIP allows multiplex variable size CIP packets to be transmitted in one variable size CIP container. The UDP/IP overhead is amortized over several CIP packets. A Large FP PDU is segmented in order to avoid IP fragmentation and to keep the transmission delay low. The CIP container can pack multiple CIP packets to improve the transmission efficiency. A CIP packet header includes a 16 bit context ID (CID), an 8 bit payload length and an 8 bit sequence number. CID is used to distinguish flows of different calls or users from high layers. Sequence number is used to reassemble segmented packets. Payload length indicates the length of CIP packet payload, which is between 1 and 245 bytes in size. The UDP/IP overhead could be compressed to improve the bandwidth efficiency [8].

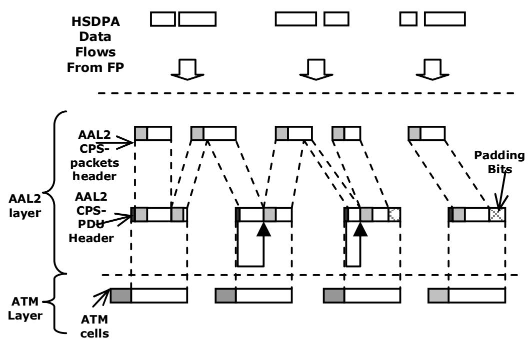

Figure 2. AAL2/ATM multiplexing structure

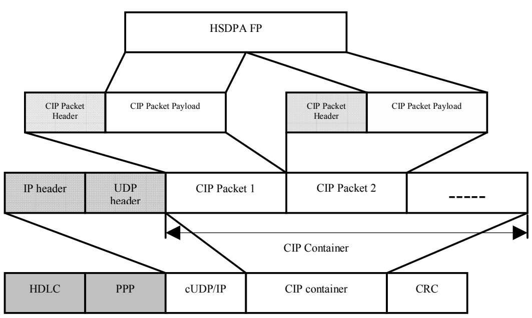

Figure 3. CIP/UDP/IP multiplexing structure

IV. TRAFFIC & SIMULATION MODELS

In this work we concentrate on bursty web traffic transmission to compare the I_{ub} links. The 3GPP standard defines data traffic models at source level. Web browsing data source models have the distinctive "ON-OFF" characteristic. The UMTS traffic model is used to develop the web browsing application [8]. The web browser generator generates a number of packets during the ON period which corresponds to the download of web pages. Web page file size is Pareto distributed with a parameter α= 1.1, mean = 12,000 bytes, minimal file size = 1858 bytes, maximal file size = 5000000 bytes. The probability density function of the pareto distribution is shown in (1).

$$f(x) = \begin{cases} \dfrac{\alpha \cdot k^{\alpha}}{x^{\alpha+1}}, & k \le x \le m \\ \dfrac{k^{\alpha}}{m^{\alpha}}, & x > m \end{cases} \qquad (1)$$

$$where \quad \alpha = 1.1, k = 1858, and \quad m = 5{,}000{,}000$$

The inter-arrival time of bursts (ON time) are geometrically distributed. The burst size distribution is controlled by the Pareto distribution. The reading time (OFF period) between two consecutive bursts is also geometrically distributed with a mean value of 12 second.

In the UTRAN HSDPA traffic is transmitted using the HS-DSCH channel. The HSDPA standard supports twelve different categories for User equipment (UE). Depending on the category supported, the maximum downlink data rate vary between 0.9 and 14.4 Mbps. In this work Category 12 UEs are simulated. We simulated a flow control algorithm to control data flow between MAC-hs and MAC-d layers (RNC to node-B). At the beginning of a call, a RNC send a request to the Node B for the HS-DSCH capacity. The Node B allocate capacity to the RNC, and indicates the maximum MAC-d PDU length, number, HS-DSCH interval and repetition rate, etc, to control user data flow according to the capacity allocated by the Node B. The HS-DSCH data is mapped on to a HS-DSCH FP data frame and transmitted immediately from the RNC to the node B. Here, we consider all allocated MAC-d PDU are sent in one FP frame and the HS-DSCH channel is used to transport web data traffic only. We assume the HS-DSCH is operating at the theoretical peak rate. Using the theoretical peak rate in each TTI (2ms), up to 10 RLC blocks are sent for every users [9][2]. The RNC simulation model is shown in Fig. 4. The HSDPA user traffic is generated using the described traffic model and then passed through a number of protocol layers. Data cells/packets are stored in the queue for transmission over the I_{ub} interface. We assume that the radio channel SNIR (Signal to Noise Interference Ratio) is high enough to support peak rate transmission.

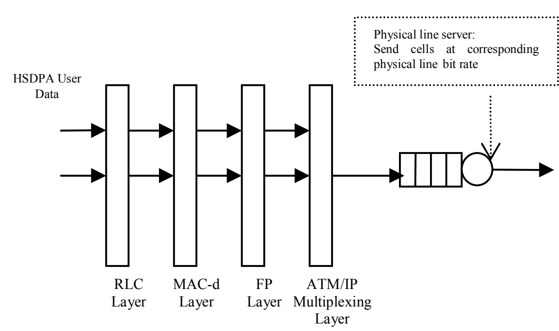

Figure 4. Multiplexing architecture at the transmitter.

V. SIMULATION RESULTS

In this work we developed a discrete event simulation model using the OPNET simulation package. The model simulates both DCH and HSDPA connections on the downlink using the traffic generator described in the previous section. For the DCH channel simulation, we used ten 64kbs data users. We have used ten HSDPA users (UE category 12) to obtain the HSDPA statistics. In each TTI, all power and code resource are allocated one HSDPA user. Data is transmitted over the air interface at the theoretical peak rate. In the simulation we use the HSDPA UE category 12 to analyze the efficiency of ATM and IP based transmission schemes. A RLC block size of 320 bits is used in the simulation with a 16 bit overhead as UE 12 category specification. Ten RLC PDUs are sent per 2ms TTI when HS-DSCH is operating at the theoretical peak rate.

Table I shows the size of a FP frame (HS-DSCH FP frame, we will refer it as the FP frame in the remainder of the text) for category 12 UE operating at the peak rate [9][2]. Table I shows the total FP frame size of 443 byte is used. To transmit the FP frame on an ATM based link the FP frame is segmented in to number of blocks and encapsulated into cells using the frame packing algorithm described in the Fig. 2. Similarly an IP packet is generated using the packing algorithm described from the Fig 3. Efficiency of an I_{ub} link transport mechanism will depend on the ratio of the payload to total transmitted bits which includes header bits. For an ATM based link the number of overhead bits transmitted for transmitting a FP frame will be higher than for an IP based link. To transmit a 443 byte FP frame an ATM based link needs to transmit 10 ATM cells giving overall link efficiency of 76%. On the other hand if the same FP frame is transmitted using a CIP/UDP/IP frame then only two IP packets are transmitted with an overall link efficiency of 97%. Similar efficiency figures will be obtained for transmitting video traffic because of the segmentation process at the lower layer. For VoIP transmissions link efficiency could be increased by aggregating number of voice of connections in a single cell or in a single IP packet. For VoIP connections when aggregation policy is used the IP connection will still offer higher link efficiency than an ATM connection particularly when the header compression technique is used.

TABLE I. FP FRAME FIELDS (BYTE)

FP overhead	7
MAC-d	10 × 42
Spares bit and Padding	10 × 1
new IE flag, DRT, and CRC etc	6
Total	443

Some initial simulation results are presented in Figs. 5 to 9. Fig. 5 shows the traffic generation pattern for DCH and HSDPA channels on the downlink. These traffic patterns were generated by using DCH and HSDPA channel scheduling schemes and ideal transmission conditions. Figure shows that traffic on the DCH channel (shown red) are appears more like periodic traffic because of regular scheduling of packets. On the other hand the because of use of short TTI and single user allocation for a short period the traffic on the I_{ub} link becomes more bursty. In the simulation we assumed that at anytime single user traffic will be transmitted from RNC to node-B for peak rate transmission on the air interface. Simulation also assumes that the RNC receives data packets from the core network and use a large buffer for storing data burst in the RNC. The node-B buffer is used for storing only current scheduled transmission burst and subsequent ARQ data. Use of a shorter node-B buffer and a longer RNC buffer also helps the handover process for the HSDPA terminals. The HSDPA standard supports a hard handover process which requires old node-B buffer flush after a handover. With a shorter node-B buffer most of the data will remain at the RNC and will be redirected to a new node-B without flushing data from the old node-B.

Figs. 6 and 7 show the queue lengths at the RNC for ATM and IP based connections respectively for HSDPA traffic. Figures show that the IP based I_{ub} link needs to use buffer for shorter periods for transmission because each IP packet is carrying a larger payload compared to ATM cells. The implication of this result is that a HSDPA based base station requires a smaller buffer at a node-B to support peak data rate. With a faster I_{ub} link it is possible to use a smaller buffer at a node-B because the RNC can respond to a node-B request quickly supporting sustainable peak rate on the air interface. Figs. 8 and 9 show the CDFs (cumulative Distribution Function) of the FP frame delays for ATM and IP based links respectively. An E1 link is used between the RNC and node-B. The ATM and IP link delays are shown in seconds and milliseconds respectively. Figures show that average delay of the IP based link is much shorter than the ATM based link. The reduction of delay on the IP link is mainly due to lower segmentation and queuing delays. Figures also show that a shorter timer_cu delay increases the ATM link delay, on the other hand IP link delay decreases. The main reason for increased ATM link delay is due to the use of extra padding bits used for transmission of cells. For the IP link multiplexing delay is the major delay component which reduces due to use of a shorter timer_cu value. The consequence of the higher delay on ATM link means the node-B needs to fetch data in advance from a RNC to transmit data at peak rate on the air interface. Hence, an ATM based RAN is unable to support HSDPA connections with peak data rate unless very large buffers are used in the node-B.

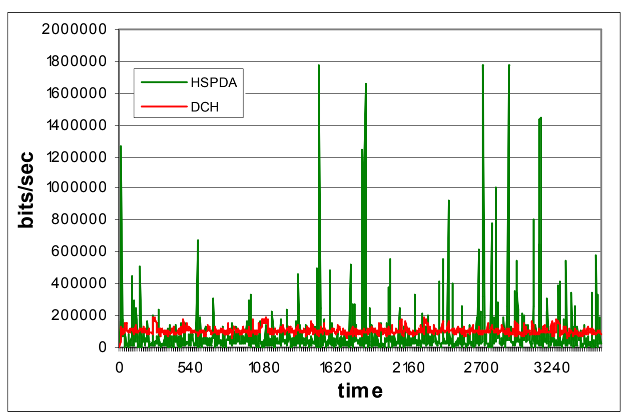

Figure 5. Traffic pattern (HSPDA and DCH) entering Iub Link

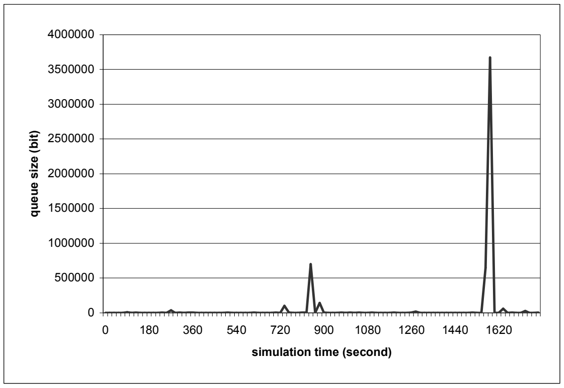

Figure 6. Queue size distribution (ATM based)

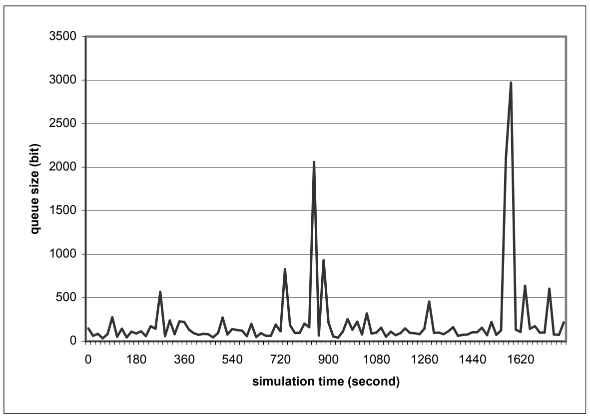

Figure 7. queue size distribution (IP based)

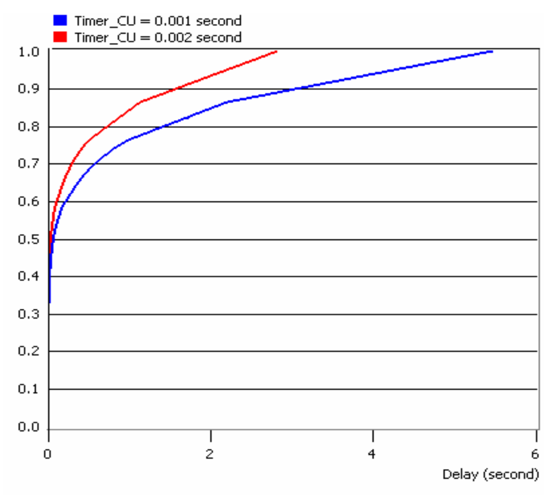

Figure 8. CDF of dealy on ATM based I_{ub} link for HSDPA

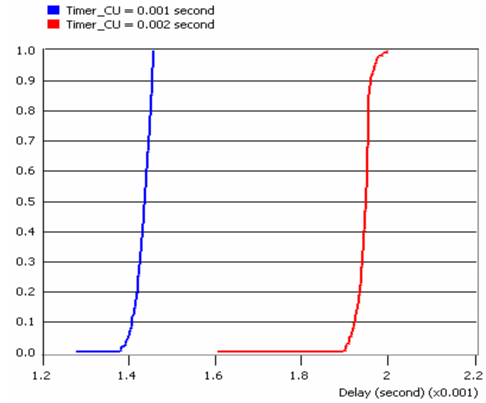

Figure 9. CDF of dealy on IP based I_{ub} link for HSDPA

VI. CONCLUSIONS

In this paper, we presented some initial performance results of AAL2/ATM and CIP/UDP/IP based I_{ub} link for HSDPA traffic. Simulation results show IP based transmission scheme with UDP/IP overhead compression is more efficient than an ATM based transmission technique to deliver HSDPA traffic as well as to support efficient handover processes for HSDPA terminals. This simulation work is based on one HS-DSCH channel, one RNC and one Node B scenario. Currently we are further developing the simulation model to support variable transmission rates on the HS-DSCH channels in micro and macro cell networks which radio transmission condition can vary significantly. The simulation model will also include an adaptive traffic scheduler for the I_{ub} link. The scheduler will allocate the I_{ub} link capacity based on the radio channel condition. The link scheduler will be controller by the node-B which will adaptively change the bandwidth allocation on the link. For example, if the throughput of an air interface drops then a node-B will proportionally slow down the data flow between node-B and the RNC to avoid buffer problems.

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