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(54) AVERAGED END-USER THROUGHPUT EVALUATION

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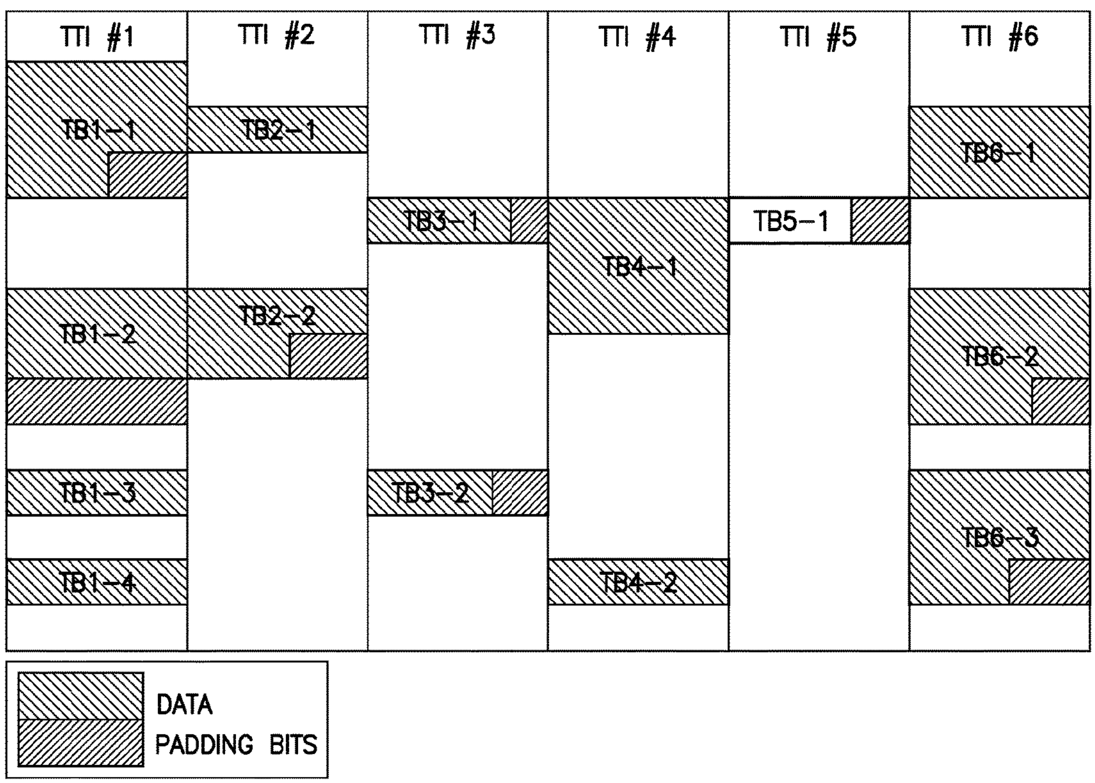
CPC ***H04W 24/08*** (2013.01); ***H04W 24/10*** (2013.01); ***H04L 43/0888*** (2013.01)

(57) **ABSTRACT**

Methods, apparatuses, and computer program products for measuring throughput as a measure of performance and/or quality of service are provided. One method comprises, over an observation period for at least one of an uplink direction and a downlink direction, measuring an amount of padding bits in each protocol data unit (PDU) that is successfully transmitted in the said direction and that carries data relevant to a given throughput measure. The method may also comprise transforming the measured amounts of padding bits to the time domain and summing the transformed amounts of padding in the time domain. The method may also comprise utilizing the summed amount of padding in the time domain to account for small data transmissions in a calculation for the given throughput measure.



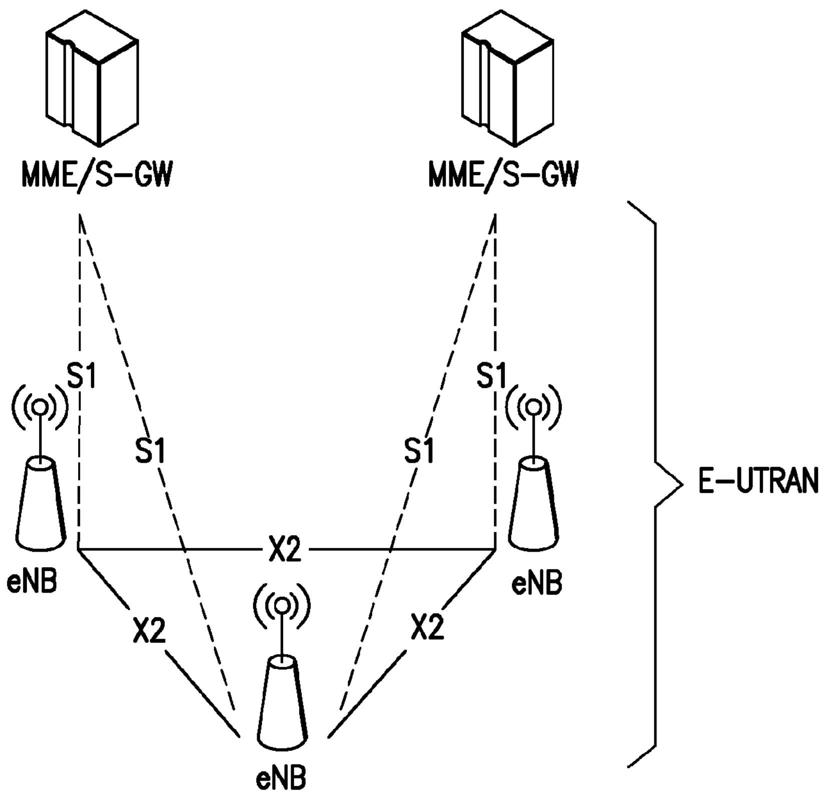


FIG.1A
PRIOR ART

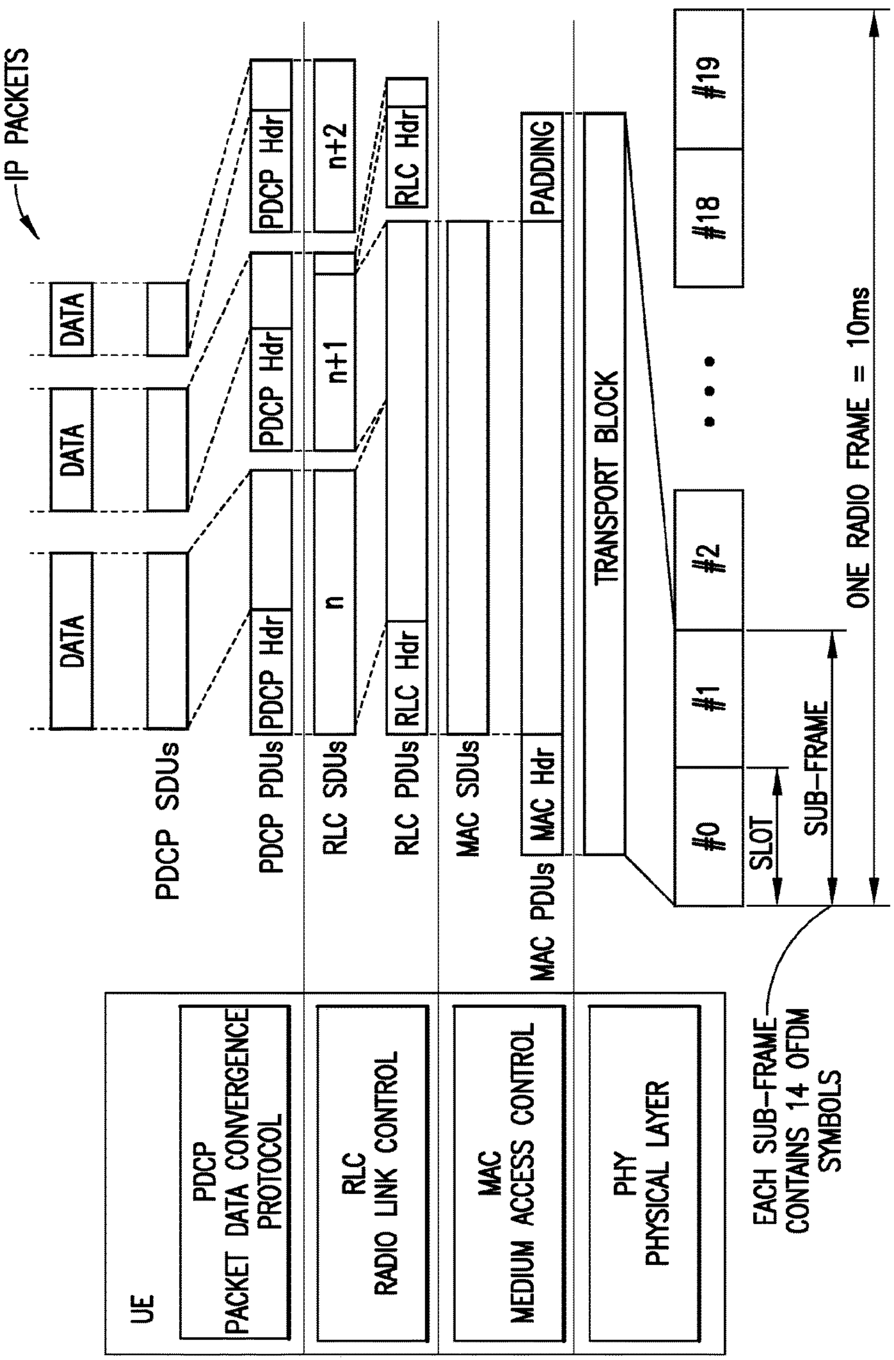


FIG.1B
PRIOR ART

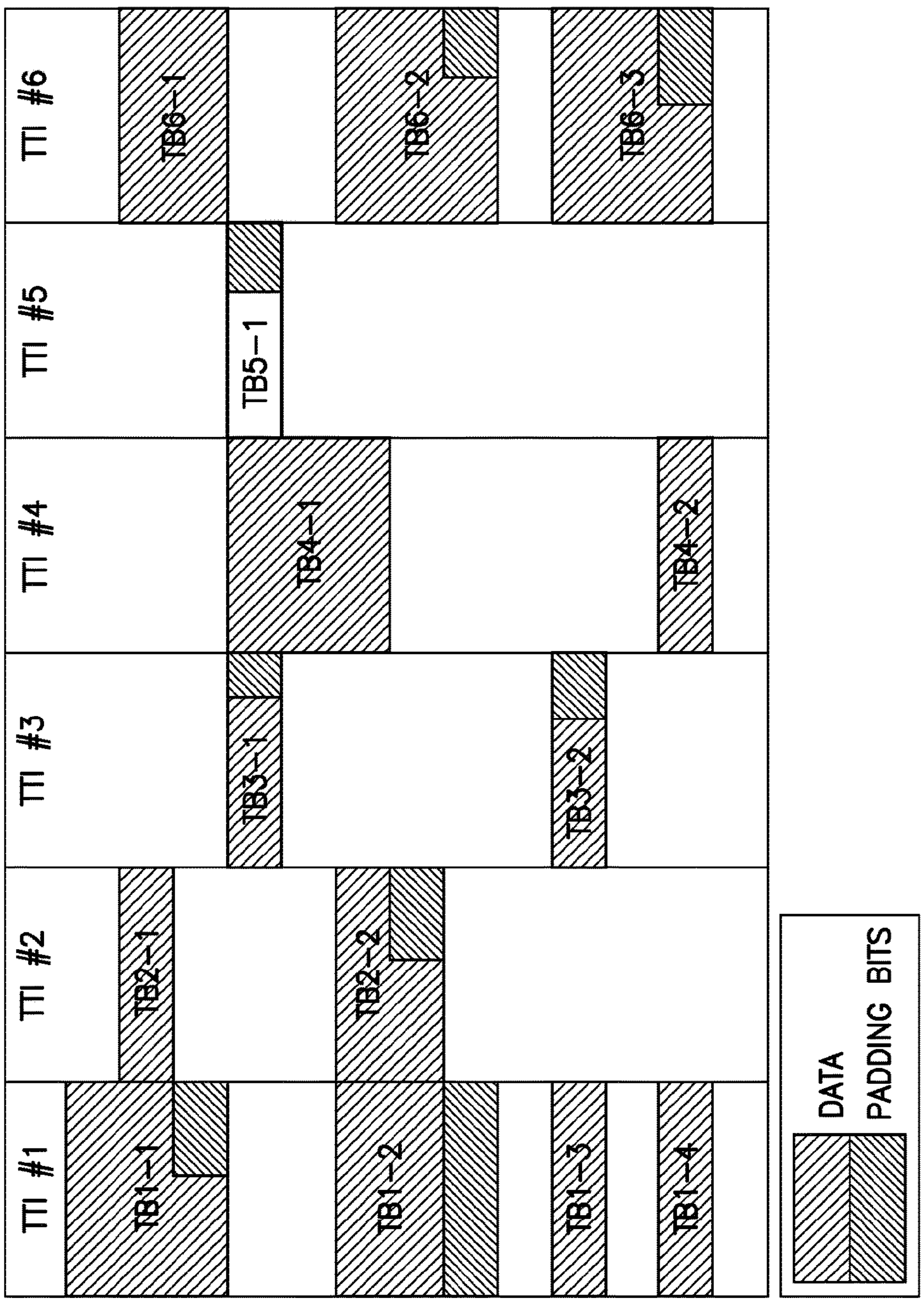

TTI #1
TTI #2
TTI #3
TTI #4
TTI #5
TTI #6
TB1-1
TB1-2
TB1-3
TB1-4
TB2-1
TB2-2
TB3-1
TB3-2
TB4-1
TB4-2
TB5-1
TB6-1
TB6-2
TB6-3
DATA
PADDING BITS

FIG.2

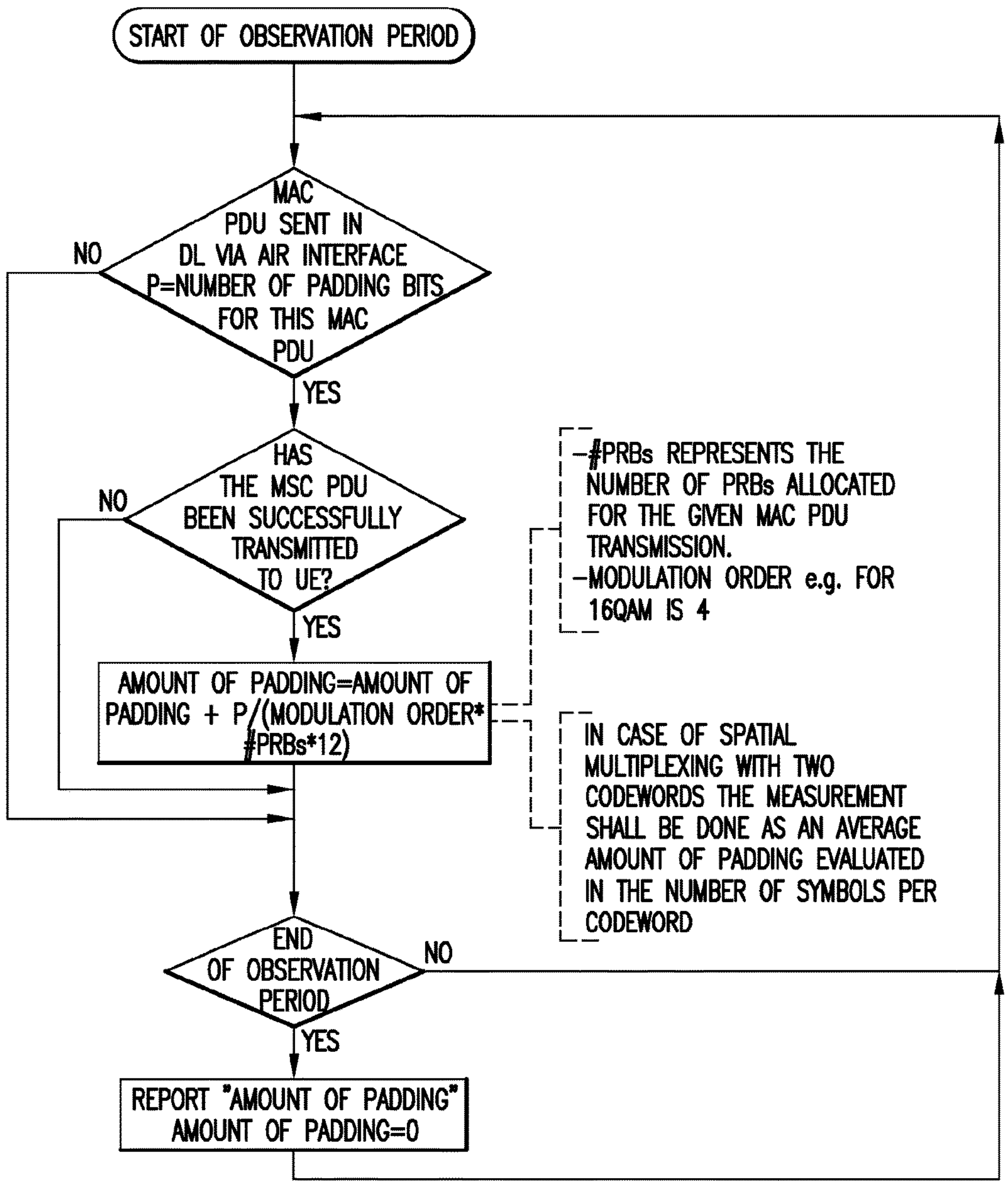

START OF OBSERVATION PERIOD
MAC PDU SENT IN DL VIA AIR INTERFACE P=NUMBER OF PADDING BITS FOR THIS MAC PDU
NO
YES
HAS THE MSC PDU BEEN SUCCESSFULLY TRANSMITTED TO UE?
NO
YES
AMOUNT OF PADDING=AMOUNT OF PADDING + P/(MODULATION ORDER* #PRBs*12)
-#PRBs REPRESENTS THE NUMBER OF PRBs ALLOCATED FOR THE GIVEN MAC PDU TRANSMISSION.
-MODULATION ORDER e.g. FOR 16QAM IS 4
IN CASE OF SPATIAL MULTIPLEXING WITH TWO CODEWORDS THE MEASUREMENT SHALL BE DONE AS AN AVERAGE AMOUNT OF PADDING EVALUATED IN THE NUMBER OF SYMBOLS PER CODEWORD
END OF OBSERVATION PERIOD
NO
YES
REPORT "AMOUNT OF PADDING" AMOUNT OF PADDING=0

FIG.3

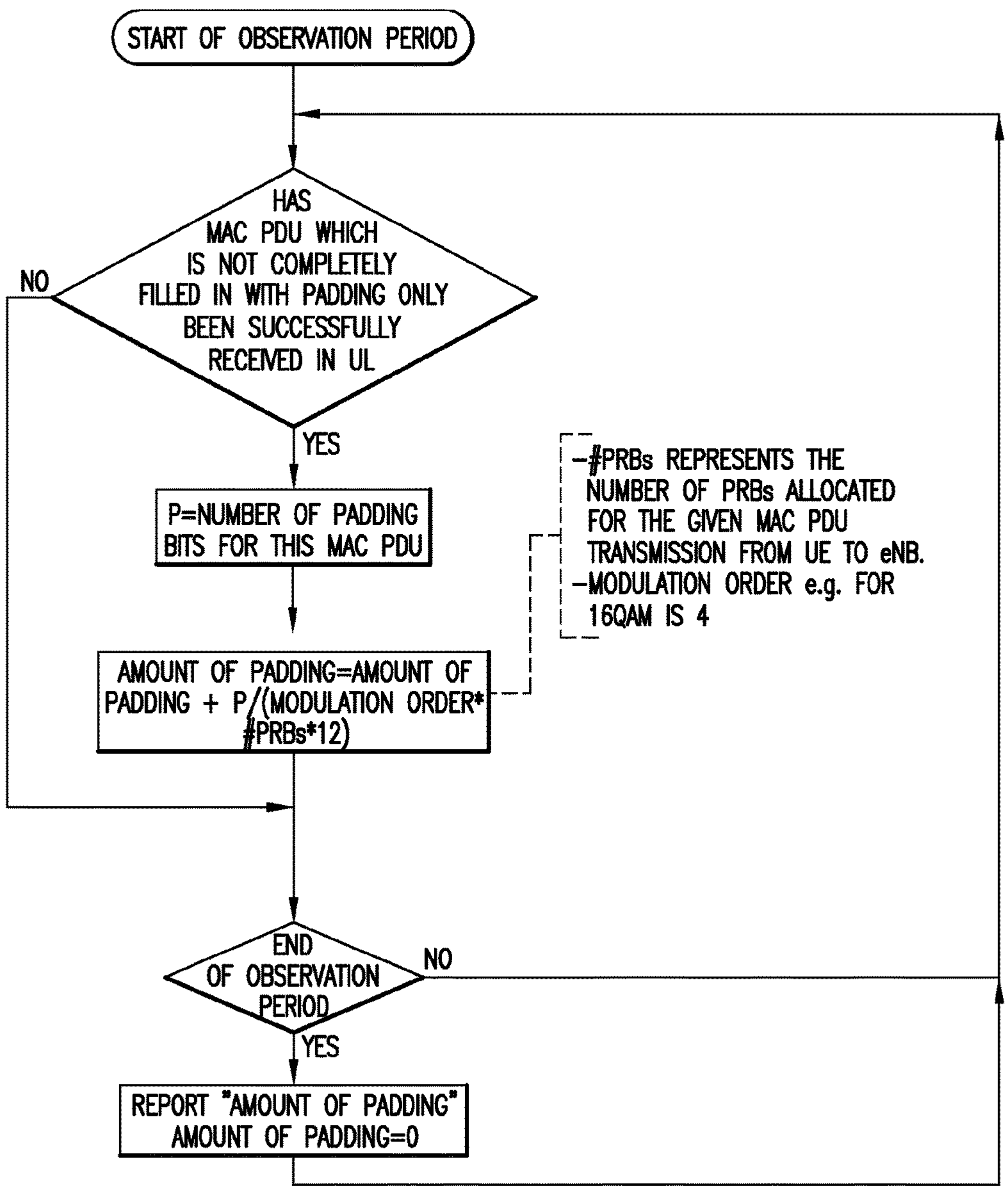

START OF OBSERVATION PERIOD
HAS MAC PDU WHICH IS NOT COMPLETELY FILLED IN WITH PADDING ONLY BEEN SUCCESSFULLY RECEIVED IN UL
NO
YES
P=NUMBER OF PADDING BITS FOR THIS MAC PDU
AMOUNT OF PADDING=AMOUNT OF PADDING + P/(MODULATION ORDER* #PRBs*12)
-#PRBs REPRESENTS THE NUMBER OF PRBs ALLOCATED FOR THE GIVEN MAC PDU TRANSMISSION FROM UE TO eNB.
-MODULATION ORDER e.g. FOR 16QAM IS 4
END OF OBSERVATION PERIOD
NO
YES
REPORT "AMOUNT OF PADDING" AMOUNT OF PADDING=0

FIG.4

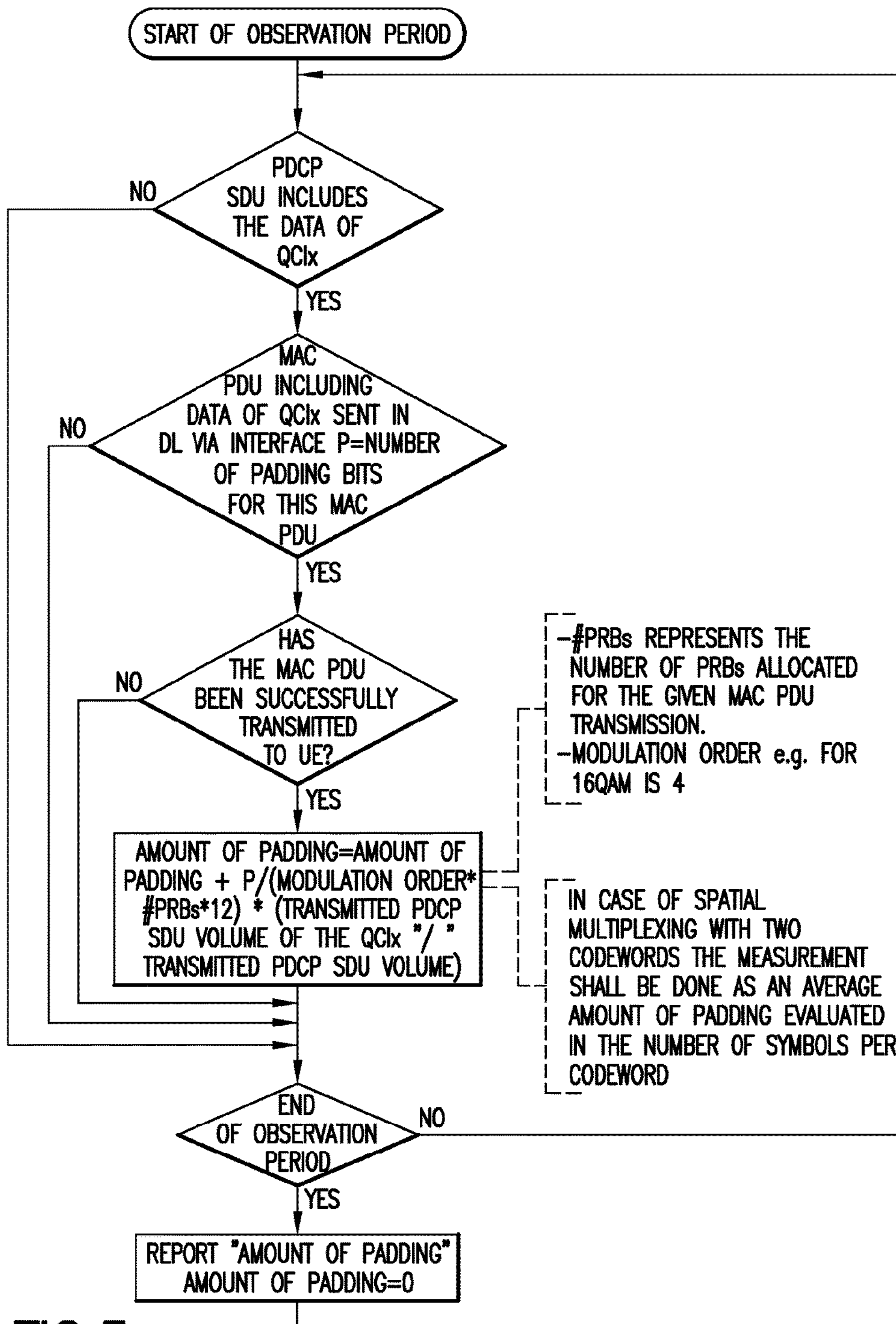

START OF OBSERVATION PERIOD
PDCP SDU INCLUDES THE DATA OF QCIx
NO
YES
MAC PDU INCLUDING DATA OF QCIx SENT IN DL VIA INTERFACE P=NUMBER OF PADDING BITS FOR THIS MAC PDU
NO
YES
HAS THE MAC PDU BEEN SUCCESSFULLY TRANSMITTED TO UE?
NO
YES
AMOUNT OF PADDING=AMOUNT OF PADDING + P/(MODULATION ORDER* #PRBs*12) * (TRANSMITTED PDCP SDU VOLUME OF THE QCIx "/ " TRANSMITTED PDCP SDU VOLUME)
–#PRBs REPRESENTS THE NUMBER OF PRBs ALLOCATED FOR THE GIVEN MAC PDU TRANSMISSION.
–MODULATION ORDER e.g. FOR 16QAM IS 4
IN CASE OF SPATIAL MULTIPLEXING WITH TWO CODEWORDS THE MEASUREMENT SHALL BE DONE AS AN AVERAGE AMOUNT OF PADDING EVALUATED IN THE NUMBER OF SYMBOLS PER CODEWORD
END OF OBSERVATION PERIOD
NO
YES
REPORT "AMOUNT OF PADDING" AMOUNT OF PADDING=0

FIG.5

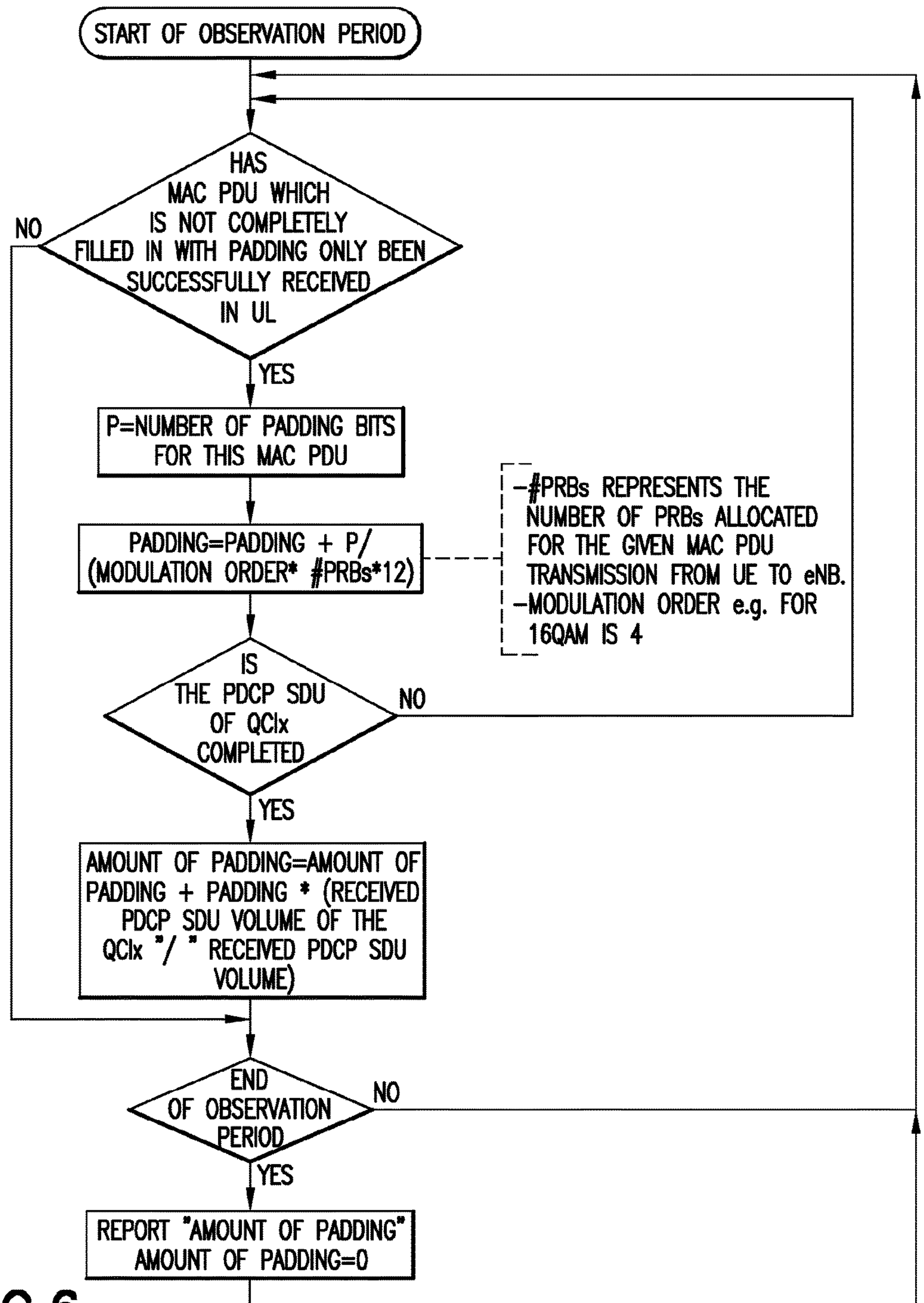

START OF OBSERVATION PERIOD
HAS MAC PDU WHICH IS NOT COMPLETELY FILLED IN WITH PADDING ONLY BEEN SUCCESSFULLY RECEIVED IN UL
NO
YES
P=NUMBER OF PADDING BITS FOR THIS MAC PDU
PADDING=PADDING + P/ (MODULATION ORDER* #PRBs*12)
–#PRBs REPRESENTS THE NUMBER OF PRBs ALLOCATED FOR THE GIVEN MAC PDU TRANSMISSION FROM UE TO eNB.
–MODULATION ORDER e.g. FOR 16QAM IS 4
IS THE PDCP SDU OF QCIx COMPLETED
NO
YES
AMOUNT OF PADDING=AMOUNT OF PADDING + PADDING * (RECEIVED PDCP SDU VOLUME OF THE QCIx "/ " RECEIVED PDCP SDU VOLUME)
END OF OBSERVATION PERIOD
NO
YES
REPORT "AMOUNT OF PADDING" AMOUNT OF PADDING=0

FIG.6

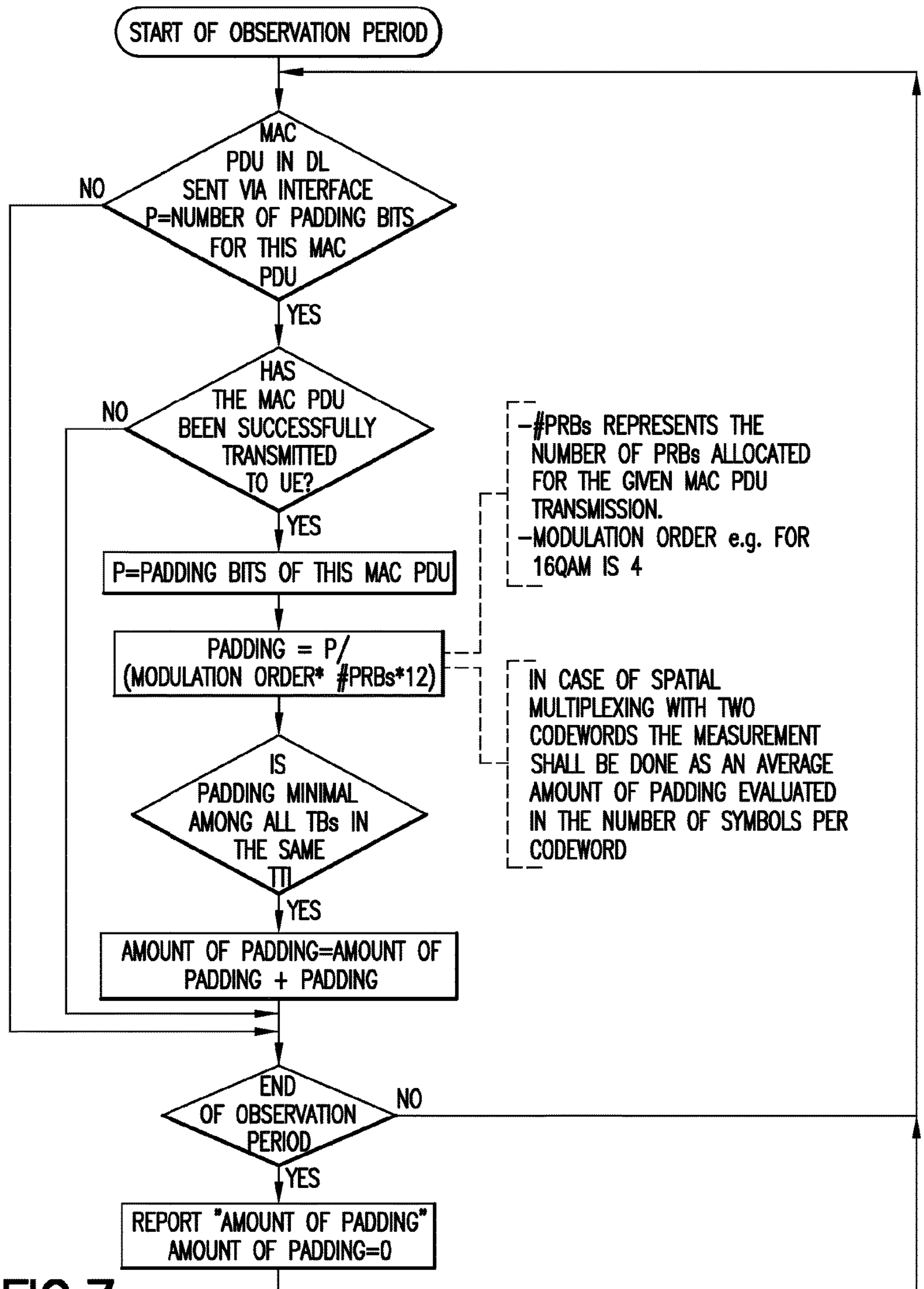

START OF OBSERVATION PERIOD
MAC PDU IN DL SENT VIA INTERFACE P=NUMBER OF PADDING BITS FOR THIS MAC PDU
NO
YES
HAS THE MAC PDU BEEN SUCCESSFULLY TRANSMITTED TO UE?
NO
YES
P=PADDING BITS OF THIS MAC PDU
PADDING = P/ (MODULATION ORDER* #PRBs*12)
–#PRBs REPRESENTS THE NUMBER OF PRBs ALLOCATED FOR THE GIVEN MAC PDU TRANSMISSION.
–MODULATION ORDER e.g. FOR 16QAM IS 4
IN CASE OF SPATIAL MULTIPLEXING WITH TWO CODEWORDS THE MEASUREMENT SHALL BE DONE AS AN AVERAGE AMOUNT OF PADDING EVALUATED IN THE NUMBER OF SYMBOLS PER CODEWORD
IS PADDING MINIMAL AMONG ALL TBs IN THE SAME TTI
YES
AMOUNT OF PADDING=AMOUNT OF PADDING + PADDING
END OF OBSERVATION PERIOD
NO
YES
REPORT "AMOUNT OF PADDING" AMOUNT OF PADDING=0

FIG.7

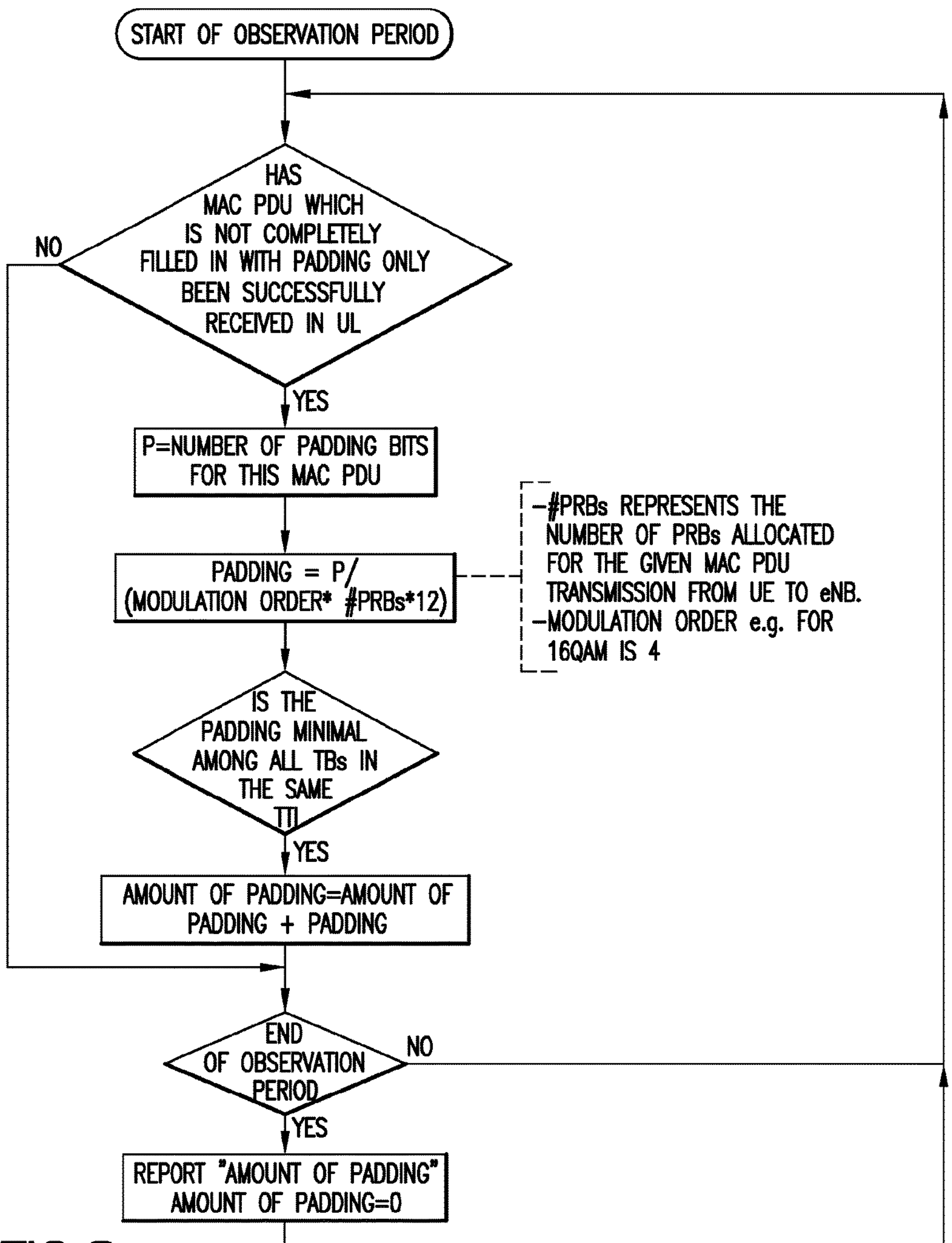

START OF OBSERVATION PERIOD
HAS MAC PDU WHICH IS NOT COMPLETELY FILLED IN WITH PADDING ONLY BEEN SUCCESSFULLY RECEIVED IN UL
NO
YES
P=NUMBER OF PADDING BITS FOR THIS MAC PDU
PADDING = P/ (MODULATION ORDER* #PRBs*12)
–#PRBs REPRESENTS THE NUMBER OF PRBs ALLOCATED FOR THE GIVEN MAC PDU TRANSMISSION FROM UE TO eNB.
–MODULATION ORDER e.g. FOR 16QAM IS 4
IS THE PADDING MINIMAL AMONG ALL TBs IN THE SAME TTI
YES
AMOUNT OF PADDING=AMOUNT OF PADDING + PADDING
END OF OBSERVATION PERIOD
NO
YES
REPORT "AMOUNT OF PADDING" AMOUNT OF PADDING=0

FIG.8

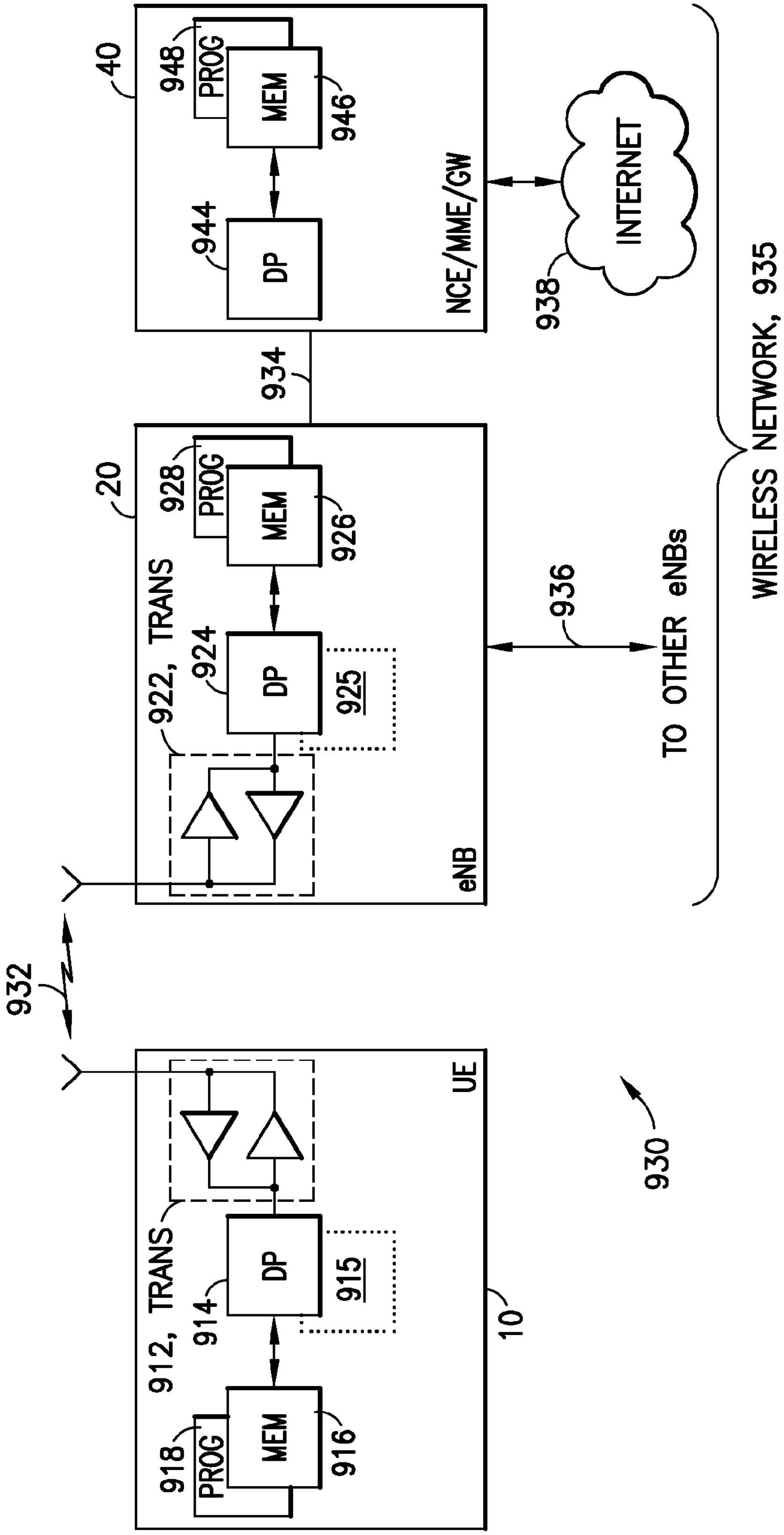

UE
10
MEM
916
PROG
918
912, TRANS
DP
914
915
932
eNB
20
922, TRANS
DP
924
925
MEM
926
PROG
928
936
TO OTHER eNBs
934
NCE/MME/GW
40
DP
944
MEM
946
PROG
948
INTERNET
938
WIRELESS NETWORK, 935
930

FIG.9

AVERAGED END-USER THROUGHPUT EVALUATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from U.S. Provisional Application No. 62/165,285, filed on May. 22, 2015. The entire contents of this earlier filed application are hereby incorporated by reference in their entirety.

TECHNOLOGICAL FIELD

[0002] The described invention relates to wireless communications, and more particularly to measuring throughput as a measure of performance and/or quality of service.

BACKGROUND

[0003] The examples herein are in the context of a wireless cellular radio network, for example E-UTRAN LTE networks, but the throughput measures herein are readily adaptable to other wireless radio access technologies. FIG. **1A** is a diagram illustrating an example of an overall architecture of such an E-UTRAN LTE system. Individual mobile devices, termed UEs, access the radio network through eNBs which can communicate directly with one another by means of an X2 interface. The eNBs are also connected by means of a S1 interface to an Enhanced Packet Core (EPC), more specifically to a Mobility Management Entity (MME) by means of a S1 MME interface and to a Serving Gateway (S-GW) by means of a S1 interface. The S1 interface supports a many-to-many relationship between MMEs/S-GW and eNBs.

[0004] One metric used to evaluate the E-UTRAN's performance is data throughput. Specifically, end user throughput is one of the Key Performance Indicators (KPIs) used to monitor quality of services as perceived by that end user (e.g., any given user equipment or UE). The services provided by E-UTRAN are based on the delivery of Internet Protocol (IP) packets, and so from the end user's point of view it is important that this or any other throughput metric accurately measures what the end user perceives to be its IP throughput.

[0005] In this regard the relevant E-UTRAN specification is 3GPP TS 36.314 section 4.1.6 and TS 32.425 section 4.4.6, which defines how to measure "IP Scheduled Throughput" per quality control indicator (QCI) and per UE. In order to consider this end user throughput independent of packet size, this measurement excludes from consideration of the volume and the active time measurements the last TTI which empties the UE's buffer. Section 4.1.7 of 3GPP TS 36.314 concerns minimization of drive tests (MDTs, in which UE's provide performance measurements to the network which in previous times were taken by roving network measurement apparatus). This section extends the "Scheduled IP Throughput" of section 4.1.6 for MDT purposes and the MDT throughput measurements follow similar principles as those set forth in section 4.1.6, except the measurements are per UE and per evolved resource allocation block (E-RAB).

[0006] A problem arises in that the Scheduled IP Throughput as defined in 3GPP TS 36.314 and 32.425 intends to measure the end user throughput for the provided services using data bursts that are large enough to require transmissions to be split across several transmission time intervals (TTIs). But in case the provided services do not meet this criterion they are completely excluded from measurement and the throughput measured according to 3GPP TS 36.314 and 32.425 counts such bursts not spanning multiple TTIs as zero data.

[0007] Such small bursts may occur for example when the amount of data is not able to fill in the whole transport block (TB) and when emptying the buffer. But it is quite common in practice that traffic in the network can be dominated by very small data bursts each sent within only one TTI, and none of these small packet bursts would qualify for measurement in the existing scheduled IP throughput counters. Embodiments of these teachings resolve this issue, and one result is improved end user throughput evaluation per UE when there is a non-negligible volume of data sent with small data bursts.

SUMMARY

[0008] One embodiment is directed to a method comprising, over an observation period for at least one of an uplink direction and a downlink direction, measuring an amount of padding bits in each protocol data unit (PDU) that is successfully transmitted in the said direction and that carries data relevant to a given throughput measure. The method may also comprise transforming the measured amounts of padding bits to the time domain and summing the transformed amounts of padding in the time domain. The method may also comprise utilizing the summed amount of padding in the time domain to account for small data transmissions in a calculation for the given throughput measure.

[0009] Another embodiment is directed to an apparatus which may include at least one processor and at least one non-transitory memory including computer program code. The at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus to, over an observation period for at least one of an uplink direction and a downlink direction, measure an amount of padding bits in each protocol data unit (PDU) that is successfully transmitted in the said direction and that carries data relevant to a given throughput measure. The apparatus may also be caused to transform the measured amounts of padding bits to the time domain and summing the transformed amounts of padding in the time domain. The apparatus may also be caused to utilize the summed amount of padding in the time domain to account for small data transmissions in a calculation for the given throughput measure.

[0010] Another embodiment is directed to a computer program embodied on a program a computer readable medium. The computer program may be configured, when run a processor, to cause the processor to perform a process comprising, over an observation period for at least one of an uplink direction and a downlink direction, measuring an amount of padding bits in each protocol data unit (PDU) that is successfully transmitted in the said direction and that carries data relevant to a given throughput measure. The process may further comprise transforming the measured amounts of padding bits to the time domain and summing the transformed amounts of padding in the time domain. The process may further comprise utilizing the summed amount of padding in the time domain to account for small data transmissions in a calculation for the given throughput measure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1**A is a prior art diagram illustrating an overall architecture of an E-UTRAN LTE radio system.

[0012] FIG. **1**B is a prior art overview of logical layers in the FDD version of LTE assuming a normal-size cyclic prefix.

[0013] FIG. **2** is a table showing an exemplary transmission diagram according to certain aspects of these teachings.

[0014] FIG. **3** is a flow diagram illustrating how to measure an amount of padding bits per UE in the downlink direction according to a particular aspect of these teachings.

[0015] FIG. **4** is a flow diagram illustrating how to measure an amount of padding bits per UE in the uplink direction according to a particular aspect of these teachings.

[0016] FIG. **5** is a flow diagram illustrating how to measure an amount of padding bits per CQI level in the downlink direction according to a particular aspect of these teachings.

[0017] FIG. **6** is a flow diagram illustrating how to measure an amount of padding bits per CQI level in the uplink direction according to a particular aspect of these teachings.

[0018] FIG. **7** is a flow diagram illustrating how to measure an amount of padding bits per cell in the downlink direction according to a particular aspect of these teachings.

[0019] FIG. **8** is a flow diagram illustrating how to measure an amount of padding bits per cell in the uplink direction according to a particular aspect of these teachings.

[0020] FIG. **9** is a diagram illustrating some components of the UE, eNB and MME shown at FIG. **1**A that are suitable for practicing the invention.

DETAILED DESCRIPTION

[0021] To overcome the small data burst measurement issue mentioned in the background section, some network operators estimate the end user throughput per UE with small data bursts by dividing the total transmitted packet data convergence protocol service data unit (PDCP SDU) volume with the total active UEs' time that there is data in its buffer. Experience shows that the reliability of results obtained this way depend on how many of the symbols in the TB is/are filled in with useful data, versus those filled only with padding bits.

[0022] FIG. **1**B puts this in context by illustrating the relevant data structures and shows an overview of the frequency division duplex (FDD) layers with a normal-length cyclic prefix (CP) in the LTE system. There are 14 symbols per TTI/subframe and two slots per subframe. The PDCP SDUs are shown in the PDCP layer. Consider an example where a TB to be transmitted with modulation order 4 and with only one PRB allocated and 200 added padding bits. This may be transformed to the case where approximately 4 symbols [200/(4*12)] are not carrying any useful data and therefore the useful data transmission takes only 10 symbols duration from the TTI, assuming a standard-length CP and 7 symbols per slot.

[0023] From the background section it is clear that when the network provides service to its end users it is not required that there be enough user data for transmission so as to fill in the selected TB. When the user data does not fill the TB, the portion not filled by user data is filled in with padding bits. On the medium access control (MAC) layer it appears that this TB with the whole selected size is transmitted, but in the PDCP layer the padding bits are not transformed to anywhere else and are simply discarded on the MAC layer by the eNB (for the case of uplink transmissions from the UE) and by the UE (for the case of downlink transmissions from the eNB).

[0024] It may appear that a straightforward solution would be to map the padding bits on the MAC layer to a respective amount of bits in the PDCP layer, in order to estimate what volume at the PDCP layer corresponds to the actual padding bits in the MAC layer. But in practice this would be quite challenging to obtain reliable results, considering that for the padding bits the eNB behaves like an emulator in order to obtain the corresponding PDCP volume.

[0025] Embodiments of these teachings solve the throughput measurement problem by addressing it in the time domain as opposed to the volume domain. As detailed below, specific example embodiments evaluate effective number of symbols in a given TTI corresponding to useful data transmission, and then use only those symbols for the end user throughput calculation. But note that when initially determining the amount of padding prior to transforming to the time domain, the padding bits are measured/counted per MAC PDU, not per symbol and the terminology 'amount of padding' (without stating 'bits') refers to the amount of padding after conversion to the time domain.

[0026] This approach can be summarized by the following points:

[0027] A. The measurement of the amount of padding is evaluated in the number of symbols in each successfully transmitted TB.

[0028] B. In relation to point A the measurement provides a sum related to padding evaluated in the number of symbols from all successfully transmitted TBs in the observation period, for example, 15 minutes if using the 3GPP default observation period.

[0029] C. In relation to points A and B, the measurement is done in both the UL and DL directions.

[0030] D. In relation to points A, B and C, the measurement is done only in the TTIs for which the UE has some data in the buffer. For example, in the UL direction the successfully transmitted TBs only filled with padding bits resulted from proactive UL scheduling would be completely excluded from this measurement.

[0031] E. In relation to points A, B, C and D, in DL the measurement is done for each successfully transmitted TB regardless of whether that TB is related to a first/original transmission or to a re-transmission.

[0032] F. In relation to point E, for the case of spatial multiplexing with two codewords the measurement is done as an average amount of padding evaluated in the number of symbols per codeword.

[0033] G. This technique can be used to measure the average IP throughput per UE, average IP throughput per QCI, and/or average IP throughput per cell (where the cell represents one eNB with or without its remote radio heads if any, one relay node, or the like).

[0034] i. To measure the averaged IP throughput per UE, the end user throughput per UE [in kilobits per second, kbps] can then be calculated as follows:

the end user throughput per UE=the PDCP SDU volume of the cell [bits]/(total active UE's time with data in its buffer [TTIs]−total amount of padding [symbols]/14), where the total amount of padding represents the sum of the amount of padding in the number of symbols from all successfully transmitted TBs in the observation period.

[0035] ii. To measure the averaged IP throughput per QCI, the end user throughput per QCI [in kbps] can then be calculated as follows:

the end user throughput per QCI=the PDCP SDU volume of the QCI/(active UEs time with data of the QCI in the buffer [TTIs]−amount of padding of the QCI [symbols]/14),

where the amount of padding of the QCI represents the estimated sum of the amount of padding in the number of symbols for the QCI from all successfully transmitted TBs in the observation period. However, the padding bits are added per TB which is per UE but not QCI, so the amount of padding per QCI can be estimated by:

[0036] a) "PDCP SDU volume of the QCI"/"PDCP SDU volume of the cell"*"total amount of padding", where "PDCP SDU volume of the QCI" and "PDCP SDU volume of the cell" represents the volume from the whole observation period;

[0037] OR

[0038] b) There can be more accurate way for estimation which may be more complex, which is x) to estimate the padding for the QCI in each UE active TTI with the data of the QCI in the buffer, by means of "PDCP SDU volume of the QCI"/"PDCP SDU volume"*"amount of padding" of each UE active TTI with the data of the QCI in the buffer; and then y) to take the sum of the result of x) (the padding for the QCI in each UE active TTI with the data of the QCI in the buffer) to get the total amount of padding of the QCI in the observed period.

[0039] iii. To measure the averaged IP throughput per cell, the cell IP throughput [kbps] is then calculated as follows:

the cell IP throughput=Total PDCP SDU volume of the cell of all UEs [bits]/(Total active time of the cell with data in the buffer [TTIs]−sum of minimal padding [symbols]/14).

[0040] For the sum of minimal padding [symbols], in the given TTI padding will only be considered if all the TBs for all the UEs scheduled in this TTI contained padding bits. So the sum of minimal padding [symbols]/represents the sum of minimal padding of the TTI in the number of symbols from all successfully transmitted TBs in the observed period. For instance, assuming the data transmission diagram shown at FIG. **2**, the Total active time with data in the buffer [TTIs] is 6; so the sum of minimal padding [symbols]:

=Σminimal padding [symbols]

=minimal padding [symbols] in TTI#3+minimal padding [symbols] in TTI#5

=min {padding [symbols] for TB3-1, padding [symbols] for TB3-2}+padding [symbols] in TB5-1

=min {padding bits of TB3-1/(#PRB for TB3-1*12*Modulation order), padding bits of TB3-2/(#PRB for TB3-2*12*Modulation order)}+padding bits of TB5-1/(#PRB for TB5-1*12*Modulation order)

[0041] The above technique does not necessarily replace the Scheduled IP Throughput as defined in 3GPP TS 36.314 and 32.425, it can be used to fill in the current gap for end user throughput measurement per UE with small data bursts where the 3GPP defined throughput does not seem to be applicable. Meanwhile and as shown above, the method also covers the case for measuring the cell IP throughput, and averaged UE throughput.

[0042] FIGS. **3-8** are flow diagrams showing the above points with more particularity; FIGS. **3-4** illustrate a process flow diagram/algorithm for calculating/measuring an amount of padding per UE in the respective downlink (DL) and uplink (UL) directions; FIGS. **5-6** illustrate a process flow diagram/algorithm for calculating/measuring an amount of padding per CQI level in the respective downlink (DL) and uplink (UL) directions; and FIGS. **7-8** illustrate a process flow diagram/algorithm for calculating/measuring an amount of padding per cell in the respective downlink (DL) and uplink (UL) directions.

[0043] These flow diagrams represent steps of a method, and/or certain code segments of software stored on a computer readable memory that embody the algorithm shown in those diagrams for finding the amount of padding that can account for small data transmissions, and actions taken by a communications entity such as a node of the LTE or other type of network when executing such software where such an entity does the throughput computations for average throughput per UE, throughput per QCI level, and/or throughput per cell.

[0044] In that regard FIG. **9** is a high level diagram illustrating some components of the communication entities shown at FIG. **1**, and additionally a user equipment (UE). In the wireless system **930** of FIG. **9** a wireless network **935** is adapted for communication over a wireless link **932** with an apparatus, such as a mobile communication device which may be referred to as a UE **10**, via a network access node, such as a Node B (base station), and more specifically an eNB **20**. The network **935** may include a network control element (NCE) **940** that may include MME/S-GW functionality, and which provides connectivity with a network, such as a telephone network and/or a data communications network (e.g., the internet **938**).

[0045] The UE **10** includes a controller, such as a computer or a data processor (DP) **914** (or multiple ones of them), a computer-readable memory medium embodied as a memory (MEM) **916** that stores a program of computer instructions (PROG) **918**, and a suitable wireless interface, such as radio frequency (RF) transceiver **912**, for bidirectional wireless communications with the eNB **20** via one or more antennas.

[0046] In general, the various embodiments of the UE **10** can include, but are not limited to, cellular telephones, personal digital assistants (PDAs) having wireless communication capabilities, portable computers having wireless communication capabilities, image capture devices such as digital cameras having wireless communication capabilities, gaming devices having wireless communication capabilities, music storage and playback appliances having wireless communication capabilities, Internet appliances permitting wireless Internet access and browsing, as well as portable units or terminals that incorporate combinations of such functions.

[0047] The eNB **20** also includes a controller, such as a computer or a data processor (DP) **924** (or multiple ones of them), a computer-readable memory medium embodied as a memory (MEM) **926** that stores a program of computer instructions (PROG) **928**, and a suitable wireless interface, such as RF transceiver **922**, for communication with the UE **10** via one or more antennas. The eNB **20** is coupled via a data/control path **934** to the NCE **40**. The path **934** may be implemented as an interface. The eNB **20** may also be coupled to another eNB via data/control path **936**, which may be implemented as an interface.

[0048] The NCE **940** includes a controller, such as a computer or a data processor (DP) **944** (or multiple ones of them), a computer-readable memory medium embodied as a memory (MEM) **946** that stores a program of computer instructions (PROG) **948**.

[0049] At least one of the PROGs **918**, **928** and **948** is assumed to include program instructions that, when executed by the associated one or more DPs, enable the device to operate in accordance with exemplary embodiments of this invention, as will be discussed below in greater detail. That is, various exemplary embodiments of this invention may be implemented at least in part by computer software executable by the DP **914** of the UE **10**; by the DP **924** of the eNB **20**; and/or by the DP **944** of the NCE **40**, or by hardware, or by a combination of software and hardware (and firmware).

[0050] For the purposes of describing various exemplary embodiments in accordance with this invention the UE **10** and the eNB **20** may also include dedicated processors, for example RRC module **915** and a corresponding RRC module **925**.

[0051] The computer readable MEMs **916**, **926** and **946** may be of any type suitable to the local technical environment and may be implemented using any suitable data storage technology, such as semiconductor based memory devices, flash memory, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory. The DPs **914**, **924** and **944** may be of any type suitable to the local technical environment, and may include one or more of general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and processors based on a multicore processor architecture, as non-limiting examples. The wireless interfaces (e.g., RF transceivers **912** and **922**) may be of any type suitable to the local technical environment and may be implemented using any suitable communication technology such as individual transmitters, receivers, transceivers or a combination of such components.

[0052] A computer readable medium may be a computer readable signal medium or a non-transitory computer readable storage medium/memory. A non-transitory computer readable storage medium/memory does not include propagating signals and may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium/memory would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing.

[0053] It should be understood that the foregoing description is only illustrative. Various alternatives and modifications can be devised by those skilled in the art. For example, features recited in the various dependent claims could be combined with each other in any suitable combination(s). In addition, features from different embodiments described above could be selectively combined into a new embodiment. Accordingly, the description is intended to embrace all such alternatives, modifications and variances which fall within the scope of the appended claims.

[0054] A communications system and/or a network node/base station may comprise a network node or other network elements implemented as a server, host or node operationally coupled to a remote radio head. At least some core functions may be carried out as software run in a server (which could be in the cloud) and implemented with network node functionalities in a similar fashion as much as possible (taking latency restrictions into consideration). This is called network virtualization. "Distribution of work" may be based on a division of operations to those which can be run in the cloud, and those which have to be run in the proximity for the sake of latency requirements. In macro cell/small cell networks, the "distribution of work" may also differ between a macro cell node and small cell nodes. Network virtualization may comprise the process of combining hardware and software network resources and network functionality into a single, software-based administrative entity, a virtual network. Network virtualization may involve platform virtualization, often combined with resource virtualization. Network virtualization may be categorized as either external, combining many networks, or parts of networks, into a virtual unit, or internal, providing network-like functionality to the software containers on a single system.

[0055] At this time but without limitation to the broader teachings herein it is expected the network would be more suitable for practicing these teachings than the UE **10**. Throughput calculations according to the algorithms and more general principles set forth above may be computed by the eNB **20**, by the NCE **40**, or by other network nodes not directly involved with signaling over the radio access network, using information provided by one or more of the entities shown at FIG. **9**. For the downlink calculations, the relevant buffer is in the eNB **20** and for the DL per UE measurements the eNB has a buffer for each UE it is currently serving. For the uplink calculations the relevant buffer is in the UE **10**, and the eNB can learn when there is data in that buffer within the UE for certain of the calculations shown above from the UE itself, such as for example through buffer status reports the UE sends uplink or other forms of requests by the UE for uplink resources over which to send its buffered data.

1-19. (canceled)

20. A method comprising:

over an observation period for at least one of an uplink direction and a downlink direction, measuring an amount of padding bits in each protocol data unit that is successfully transmitted in the said direction and that carries data relevant to a given throughput measure;

transforming the measured amounts of padding bits to the time domain and summing the transformed amounts of padding in the time domain; and

utilizing the summed amount of padding in the time domain to account for small data transmissions in a calculation for the given throughput measure.

21. The method according to claim **20**, wherein:
each of the protocol data units is a medium access control protocol data unit; and
the calculation for the given throughput measure, when utilizing the summed amount of padding, accounts for data that is transmitted in bursts spanning at least one transmission time interval.

22. The method according to claim **21**, wherein measuring the amount of padding bits comprises:
transforming the padding bits that are measured in the protocol data units into the time domain according to modulation order and number of physical resource blocks used in each transmission time interval in the respective medium access control protocol data unit for an user equipment.

23. The method according to claim **22**, wherein in case of spatial multiplexing with two codewords measuring the amount of padding bits comprises determining an average amount of padding bits per codeword.

24. The method according to claim **20**, wherein:
the given throughput measure is average throughput per user equipment; and
each of the said protocol data units is a medium access control protocol data unit characterized by there being data in a user equipment buffer for the said direction.

25. The method according to claim **24**, wherein an end user throughput per user equipment is calculated as follows:

the end user throughput per user equipment=the packet data convergence protocol service data unit volume of the cell [bits]/(total active user equipment's time with data in its buffer [transmission time intervals]−total amount of padding [symbols]/14),

where the total amount of padding represents the sum of the amount of padding in the number of symbols from all successfully transmitted transport blocks in the observation period.

26. The method according to claim **20**, wherein:
the given throughput measure is throughput per quality control indication level; and
measuring an amount of padding in each of a given ones of the protocol data units comprises adjusting an accumulated number of padding bits in the given protocol data unit to account for modulation order and number of physical resource blocks occupied by the protocol data unit, and to account for transmitted volume of the given protocol data unit relative to a transmitted volume of a packet data convergence protocol service data unit carrying the given protocol data unit.

27. The method according to claim **20**, wherein:
the given throughput measure is throughput per cell; and
each of the protocol data units that carries data relevant to the given throughput measure is restricted to those protocol data units in a transmission time interval for which all transport blocks for all scheduled user equipments contain padding bits.

28. The method according to claim **27**, wherein the throughput per cell is cell IP throughput in kbps and is calculated as follows:

the cell IP throughput=Total packet data convergence protocol service data unit volume of the cell of all user equipments [bits]/(Total active time of the cell with data in the buffer [transmission time intervals]−sum of minimal padding [symbols]/14).

29. A non-transitory program storage device readable by a machine, tangibly embodying a program of instructions executable by the machine for performing operations comprising:
over an observation period for at least one of an uplink direction and a downlink direction, measuring an amount of padding bits in each protocol data unit that is successfully transmitted in the said direction and that carries data relevant to a given throughput measure;
transforming the measured amounts of padding bits to the time domain and summing the transformed amounts of padding in the time domain; and
utilizing the summed amount of padding in the time domain to account for small data transmissions in a calculation for the given throughput measure.

30. An apparatus comprising:
at least one processor; and
at least one non-transitory memory including computer program code, the at least one memory and the computer program code configured, with the at least one processor, to cause the apparatus to:
over an observation period for at least one of an uplink direction and a downlink direction, measure an amount of padding bits in each protocol data unit that is successfully transmitted in the said direction and that carries data relevant to a given throughput measure;
transform the measured amounts of padding bits to the time domain and summing the transformed amounts of padding in the time domain; and
utilize the summed amount of padding in the time domain to account for small data transmissions in a calculation for the given throughput measure.

31. The apparatus according to claim **30**, wherein:
each of the protocol data units is a medium access control protocol data unit; and
the calculation for the given throughput measure, when utilizing the summed amount of padding, accounts for data that is transmitted in bursts spanning at least one transmission time interval.

32. The apparatus according to claim **31**, wherein the at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus to measure the amount of padding bits by at least:
transforming the padding bits that are measured in the protocol data units into the time domain according to modulation order and number of physical resource blocks used in each transmission time interval in the respective medium access control protocol data unit for an user equipment.

33. The apparatus according to claim **32**, wherein in case of spatial multiplexing with two codewords, the at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus to measure the amount of padding bits by at least determining an average amount of padding bits per codeword.

34. The apparatus according to claim **30**, wherein:
the given throughput measure is average throughput per user equipment; and
each of the said protocol data units is a medium access control protocol data unit characterized by there being data in a user equipment buffer for the said direction.

35. The apparatus according to claim **34**, wherein the at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus to calculate an end user throughput per user equipment as follows:

the end user throughput per user equipment=the packet data convergence protocol service data unit volume of the cell [bits]/(total active user equipment's time with data in its buffer [transmission time intervals]−total amount of padding [symbols]/14),

where the total amount of padding represents the sum of the amount of padding in the number of symbols from all successfully transmitted transport blocks in the observation period.

36. The apparatus according to claim **30**, wherein:

the given throughput measure is throughput per quality control indication level; and

the at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus to measure an amount of padding in each of a given ones of the protocol data units by adjusting an accumulated number of padding bits in the given protocol data unit to account for modulation order and number of physical resource blocks occupied by the protocol data unit, and to account for transmitted volume of the given protocol data unit relative to a transmitted volume of a packet data convergence protocol service data unit carrying the given protocol data unit.

37. The apparatus according to claim **30**, wherein:

the given throughput measure is throughput per cell; and

each of the protocol data units that carries data relevant to the given throughput measure is restricted to those protocol data units in a transmission time interval for which all transport blocks for all scheduled user equipments contain padding bits.

38. The apparatus according to claim **37**, wherein the throughput per cell is cell IP throughput in kbps and is calculated as follows:

the cell IP throughput=Total packet data convergence protocol service data unit volume of the cell of all user equipments [bits]/(Total active time of the cell with data in the buffer [transmission time intervals]−sum of minimal padding [symbols]/14).

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