(54) Title: SYSTEM AND METHOD FOR AUTONOMOUS DISCOVERY OF PEAK CHANNEL CAPACITY IN A WIRE-LESS COMMUNICATION NETWORK
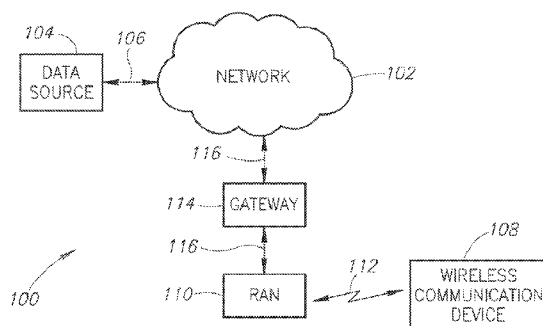
FIG.1

(57) Abstract: A wireless device includes a data structure that relates peak channel capacity to the quality of the wireless communication Sink. The wireless communication link quality forms an index to indicate the expected peak channel capacity for that particular quality value of the wireless communication link. The wireless device uses the data storage structure to determine an expected data transfer throughput based on the quality of the wireless communication link. A transfer rate Sower than expected may indicate congestion in the core network or the RAN. in this case, the network may slow the data delivery from the data source or temporarily suspend delivery. Conversely, low data throughput may be the result of a poor quality wireless communication link. If the data structure indicates that the data throughput corresponds to the expected throughput for the quality value of the wireless communication link, the system need not take any steps to reduce congestion.

SYSTEM AND METHOD FOR AUTONOMOUS DISCOVERY OF PEAK CHANNEL CAPACITY IN A WIRELESS COMMUNICATION NETWORK

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BACKGROUND OF THE INVENTION

Field of the Invention

The present disclosure is directed to a system and method for autonomous

10   discovery of peak channel capacity in a wireless communication network and, more

specifically, to techniques for a wireless communication device to independently

discover the peak channel capacity of a radio link coupling it to a communication

network.

Description of the Related Art

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Wireless communication networks comprise a radio access network (RAN) and a

core network (CN). Although different terminology may be used for different systems,

the RAN is generally the portion of a telecommunication network that communicates

with wireless communication devices, sometimes referred to as user equipment (UE),

20   mobile station (MS), mobile device or the like. For purposes of the present discussion,

the terms RAN, UE, MS, and the like may be used interchangeably with other similar

terms describing the same functionality.

While the RAN includes the radio link between a base station and the wireless

communication devices, the CN may be implemented in a variety of fashions. The CN

25   may include microwave or other wireless links. It typically also includes fiber optics,

hardwire connections and the like.

Downloading a data file from the CN to a wireless communication device is a

common activity. The data file may be, by way of example, a multimedia file. Files of

this type are often quite large and present the real possibility of causing congestion in

30   the communication network. When a wireless communication device requests a data

file, the wireless communication device has little control over the rate at which the data

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file is transferred. A slow data transfer rate may be the result of a poor radio link between the base station and the wireless communication device. Alternatively, the slow data transfer rate may be result of congestion in the CN or at the RAN. Congestion at the RAN may occur, for example, if the base station is communicating with a large number of devices and response times are slow.

In an effort to avoid congestion of the communication network, a network control element may instruct the data source (e.g., a server) to slow down the data transfer rate to avoid the undesirable congestion. As noted above, the slowed data transfer rate may be a result of a poor radio link or actual network congestion. If the slow data transfer rate is the result of a poor radio link, sending a command to the data source to slow down the transfer rate does not relieve congestion in the network and does not improve over all data throughput. On the other hand, if a slow data transfer rate is the result of network congestion, sending a back-off command to the data source can relieve network congestion. Thus, those skilled in the art will appreciate that it is important to determine the cause of the low data transfer rate. The present invention provides this and other advantages, as will be apparent from the following detailed description and accompanying figures.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Figure 1 illustrates a system architecture used in the implementation of the present disclosure.

Figure 2 is illustrates the operation of a radio access network and multiple base stations constructed in accordance with the system of Figure 1.

Figure 3 illustrates an area of coverage for a base station.

Figure 4 is a graph illustrating a data throughput for a single user, using multiple codes.

Figure 5 is a graph illustrating data throughput for a single code as a function of carrier energy to noise plus interference.

Figure 6 is a graph illustrating LTE data throughput as a function of CINR for various modulation schemes and rates.

Figure 7 is a graph illustrating spectral efficiency for various LTE implementations.

Figure 8 is a graph illustrating instantaneous values of CINR as a function of time, as well as average CINR data for one second averages.

Figure 9 is a bar graph illustrating peak throughput values as a function of CINR.

Figure 10 is a graph illustrating alternate linear and second order interpolation values used for interpolating throughput data as a function of CINR.

Figure 11 is a bar graph similar to Figure 9, but illustrating peak throughput values as a function of CINR using various interpolations.

DETAILED DESCRIPTION OF THE INVENTION

The present disclosure is directed to a system and method whereby an individual wireless communication device measures a quality value related to the quality of the radio signal connecting the device to a base station. For a particular signal quality level, an associated peak capacity value is determined for that communication link. Similar measurements are performed at other quality signal level values to construct a table or other data storage structure that can equate the quality of the radio link with a maximum data throughput capacity.

Once such a table is constructed, the wireless communication device, in a subsequent communication, can determine the expected data throughput capacity based on the current quality of the radio link. If the actual transfer rate is below the expected throughput capacity, it may be presumed that the slow data transfer rate is the result of congestion. Alternatively, if the data transfer rate is at or about the expected data transfer rate for the quality value of the radio link, there is no congestion in the communication network and there is nothing that can be done to improve the date transfer rate until the quality of the radio link improves.

As discussed above, this is a critical distinction. Prior art systems sometimes identify congestion simply on the basis of a low data transfer rate. However, the low data transfer rate can be caused by actual congestion in the network or by a poor radio link. If one assumes that a low data transfer rate is due solely to network congestion, the network may be instructed to slow down its transfer to avoid network congestion

when, in fact, none exists. A poor quality radio link is not equivalent to network congestion.

Figure 1 illustrates a system 100 in which a network 102 is shown in simplified form. The network 102 may be a private core network, such as is typical with a

5   telecommunication network service provider. Alternatively, the network 102 may include a portion of a wide area public network, such as the Internet. In Figure 1, a data source 104 is illustrated as coupled to the network 102 via a communication link 106. The data source 104 contains a data file to be transferred to a requesting device via the network 102. As illustrated in Figure 1, a wireless communication device 108 will

10   request the data file from the data source 104. The wireless communication device 108 may be any form of known communication devices ranging from mobile computing devices, such as a laptop computer, computing tablet, iPad™ or the like. The wireless communication device 108 may also be a Smartphone or other known form of communication device capable of receiving and processing a data file received from the

15   data source 104.

The wireless communication device 108 is coupled to a radio access network (RAN) 110 via a wireless communication link 112, which may be referred to herein as a radio link. It is the quality of the wireless communication link 112 that will be the primary focus of the present disclosure.

20   The RAN 110 is coupled to the network 102 via a gateway 114 and various communication links 116. For the sake of clarity, other conventional network components, such as firewalls, routers, and the like are omitted from Figure 1.

Figure 2 provides additional details of the RAN 110 and illustrates a base station 120 and a base station 122. Each base station (e.g., the base stations 120-122) has an

25   area of coverage 124, illustrated in Figure 3. As those skilled in the art will appreciate, the area of coverage 124 may vary somewhat based on the transmitter power in the base station, the overlap in coverage with other adjacent base stations, and barriers (man-made or natural terrain) that may block certain areas of coverage. In addition, the area of coverage 124 is typically subdivided into cell sectors or other sub-cells, such as

30   the sectors 126-130 illustrated in Figure 3. Those skilled in the art will appreciate that the location of the wireless communication device 108 in close proximity with the base

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station 120 will generally provide a better quality signal than if the wireless communication device 108 is located at an edge of the area of coverage 124 at some distance from the base station 120. As will be discussed in greater below, signal quality may be adversely affected by the distance from the base station to the wireless

5   communication device, or by blockage of the signal by terrain or man-made structures. In addition, the quality of the wireless communication link 112 may be adversely affected by interference and other noise sources.

Returning to Figure 2, it should be noted that the wireless communication device 108 is illustrated as communicating with the base station 120 via the wireless

10   communication link 112 and communicating with the base station 122 via a wireless communication link 132. In operation, the wireless communication device 108 can sometimes communicate with multiple base stations simultaneously. Alternatively, Figure 2 can functionally illustrate the operation of the system 100 as the wireless communication device 108 moves out of range of the base station 120 and into range of

15   the base station 122, as is common with mobile wireless communication devices. As the wireless communication device moves further away from the base station 120, the quality of the wireless communication link 112 will generally decrease. Conversely, the quality of the wireless communication link 132 will generally increase as the wireless communication device 108 moves closer to the base station 122.

20   The base stations 120 and 122 are communicatively coupled to an optional base station controller (BSC) 136 via communication links 138 and 140, respectively. Depending on the particular system implementation, the BSC 136 may control only a single base station or may control a greater number of base stations. The communication links 138-140, as well as the communication link 116, may sometimes

25   be referred to as a backhaul coupling the base stations to the network 102 (see Figure 1). (Some networks, such as LTE, can be implemented without the BSC 136.)

With a general description of the architecture of the system 100, various ways of measuring the quality of the wireless communication link 112 may now be discussed in greater detail.

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RF Signal Metrics

There are several RF Signal Metrics that could potentially be used to estimate the peak possible throughput on a wireless channel. The metrics examined herein are received signal strength index (RSSI), carrier to interference plus noise ratio (CINR), and channel quality index (CQI).

5   The factors that influence the rate at which a wireless device can receive data include the following:

Received Signal Strength Indication (RSSI)

At first glance it would appear that the RSSI should be a good indicator of the instantaneous throughput possible on a wireless channel. It would be expected that the stronger the wireless signal received from the serving base station at the mobile device, the better the throughput should be.

This is true only in the case where there is no co-channel interference. When there is co-channel interference present in the network (as is usually the case in cellular wireless networks), then this will reduce the possible throughput.

If an assumption of no interference is made then the RSSI can be used in combination with a thermal noise power estimate to generate a signal to noise ratio (SNR) estimate that can be used in lieu of a CINR reading.

$$SNR = \frac{RSSI}{Thermal\ Noise\ Power}$$

If there is no interference present, this SNR can then be mapped to a peak instantaneous throughput. However if interference is present, the throughput estimated from the SNR mapping will be higher than the peak throughput the channel is physically capable of achieving at that time.

Carrier to Interference plus Noise Ratio (CINR)

The CINR is perhaps the best indicator of the achievable throughput in a wireless system. The CINR is defined as follows:

$$CINR = \frac{Received\ Power\ from\ Serving\ Base\ Station}{Interference\ Power + Noise\ Power}$$

where:

- The received power from the serving base station is the signal level seen at the mobile device from the serving base station. Depending on the particular wireless technology, the receive power may be:

  o Total power received from the serving base station (e.g., as in GSM)

  o Power on reference signals from the serving base station (e.g., as in LTE, WiMAX)

  o Power on a CDMA code (e.g., as in W-CDMA, CDMA2000, HSDPA, 1xEV-DO, etc.)

- The interference power is the amount of signal received from other base stations in the wireless network that are operating on the same frequency channels as the serving base station

- The noise power is power of the thermal background noise received at the mobile device

Throughout this document we use the term CINR in a generic fashion. It should be noted that the terminology used for a serving signal power to interference signal power ratio can be vary depending on the wireless technology under discussion.

- In CDMA networks, the value Ec/Io (received power per chip divided by interference power spectral density) is used as the CINR.

- In LTE networks, a CINR value is not reported. Instead a related ratio, the RSRQ (Reference Signal Received Quality), is reported from the mobile devices to the base station.

Mapping between CINR and throughput

Here we present some examples of the mapping between CINR and throughput for several technologies. These mappings are based on published graphs and tables and can be used in algorithms for estimating peak channel throughput from a CINR metric.

Figure 4 (from (Holma & Toskala, 2006)) shows a plot of the signal to interference plus noise ratio (SINR) on the High Speed Downlink Shared Channel (HS-

DSCH). The peak throughput in this case is 10.7Mbps, consistent with the performance of Rel. 5 HSDPA. Similar plots can be obtained for Rel. 6/7 HSDPA. The data from Figure 4 is shown in tabular form in Table 1 below.

SINR (dB)	Number of Codes		
	5	10	15
-10	0.05	0.05	0.05
-5	0.1	0.1	0.1
0	0.2	0.2	0.2
5	0.5	0.6	0.6
10	1.0	1.2	1.3
15	1.8	2.7	3
20	2.7	4.3	5.4
25	3.2	5.7	7.9
30	3.5	6.6	9.4
35	3.6	7.0	10.1
40	3.7	7.1	10.4

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Table 1 - HSDPA performance table: data rate (Mbps)
dependence on SINR for various numbers of codes

Table 1 shows how even though the peak throughput of HSDPA is 10.4Mbps, the actual throughput of a particular UE device may be limited based on the number of

10   codes it is capable of receiving. Therefore specific capabilities of the wireless communication device 108 (see Figure 1) also need to be taken into account when looking at the mapping between CINR and throughput.

Figure 5 (from (3rd Generation Partnership Project, 2001-03)) shows a similar mapping as in Figure 4, but this time the plot is of Ec/Io vs. throughput. The difference

15   between the Ec/Io from Figure 5 and SINR from Figure 4 is that Ec/Io refers to the carrier to noise plus interference ratio for a single HSDPA code while the SINR refers to the carrier to noise plus interference ratio for multiple codes.

Figure 6 (from (3rd Generation Partnership Project, 2006)) shows the Downlink
LTE throughput vs. Es/No (SNR) for the 2x2 MIMO case of LTE in a 20MHz channel.
Es/No refers to the received symbol power divided by the normalized noise power. In a
deployed system the noise power would be the sum of the thermal noise power plus

5   interference power.

The peak throughput derived from the plot in Figure 6 is taken as the peak
throughput achieved for all modulation and coding schemes for a given Es/No. For
example, the peak throughput for Es/No = 20dB is ~87Mbps using the 64QAM, rate 2/3
coding.

10   Figure 7 (from Mogensen, et al., 2007) shows a plot of the Geometry Factor (G-
Factor) vs. spectral efficiency for various flavors of LTE. In 3GPP nomenclature, the G-
Factor is the total power from the serving base station divided by the sum of the noise
plus interference power – i.e., the CINR.

Figure 7 shows how the mapping from CINR to throughput can vary depending

15   on the number of transmitters, number of receivers and the types of algorithms used in
the system.

It should also be noted that the vertical axis in Figure 7 is in units of bits per
second per Hertz. LTE is different from previous 3GPP wireless communication
protocols in that it supports variable channel bandwidths. In order to convert from bits

20   per second per hertz to a peak throughput, it is necessary to multiply by the actual
channel bandwidth. It will also likely be necessary to take control channel signaling
overhead into account in the conversion.

Table 2 below (from (Hwang, Refaei, Choi, Kim, Sohn, & Choi)) shows a
mapping from Ec/Nt for the 1x EV-DO Rev. 0 wireless communication protocol. In this

25   case, Nt is the thermal noise power of the system and Ec is the received power of a
single code. Ec/Io can be used in place of Ec/Nt. The Rev. A wireless communication
protocol is capable of a slightly higher peak throughput at a higher Ec/Io.

Raw kbps	Ec/Nt (dB)
Null Rate	n/a
38.4	-11.5
76.8	-9.7
153.6	-6.8
307.2	-3.9
307.2	-3.8
614.4	-0.8
614.4	-0.6
921.6	1.8
1228.8	3.7
1228.8	3.8
1843.2	7.5
2457.6	9.7
1536.0	Rev. A
3072.0	Rev. A

Table 2 - 1x Ev-DO Ec/Nt vs. Throughput

Channel Quality Indicator

When a base station has data to transmit to a mobile station, it needs to know what is the appropriate modulation and coding scheme (MCS) to apply to the data so that it successfully arrives at the mobile station and utilizes the communication channel as efficiently as possible. This process is known as adaptive MCS selection.

There are many approaches that have been taken to implement adaptive MCS. Generally, some form of feedback is required from the mobile device to the base station for it to make intelligent decisions about the modulation and coding scheme to employ. The types of data that are usually fed back to the base station are:

- CINR
- Block error indications
- Channel Quality Indicator

The last of these pieces of feedback – the channel quality indicator (CQI) – can be thought of as an instruction from the mobile station to the base station of the optimal MCS to be used by the base station when transmitting to the mobile station. The CQI generally maps directly to a particular modulation and coding scheme. The mobile

5   station decides on the appropriate MCS/CQI based on the channel conditions that it observes and the device capabilities. This decision can be based upon the instantaneous CINR, and can incorporate other information such as the block error rate for a given MCS or ratio of block ACK/NACK.

If the CQI decisions could be made available (for example to applications running

10 on mobile units), this could provide a very accurate indication of the peak throughput at which the mobile station is capable of receiving at any given time. Since CQI messages are generally fed back to a serving base station at a rate of several hundred CQI messages per second, some filtering of the CQI estimates would be required in order to arrive at an average rate over a period of seconds.

15   The CQI value can be mapped directly to an instantaneous peak channel throughput. For variable bandwidth protocols such as LTE or WiMAX, it is necessary to know the operating channel bandwidth for this conversion to convert from the CQI (which represents a Modulation and Coding Scheme, independent of bandwidth) to a throughput.

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Algorithms to determine a peak throughput from RF metrics

Here we discuss several approaches that can be taken to making a peak throughput estimate using the RF metrics discussed above. Although the CINR RF metric is used, for example, it is understood that the same approach could be used with

25 other types of RF metrics including RSSI and CQI or other similar RF metrics that quantify the channel radio quality and are related in a deterministic way to the peak channel throughput. These metrics may be referred to generically as a quality value for the radio link.

Direct mapping of CINR to instantaneous peak throughput

As shown above, there is a strong correlation between the instantaneous peak throughput and the CINR. If we know the relationship between CINR and throughput for a particular wireless communication technology then a simple lookup table can be used to look up the device throughput based on the CINR.

There are, of course, some implementation details that also have to be taken into account. These details are explored in the following sub-sections.

Averaging the CINR

Figure 8 shows a plot of instantaneous CINR vs. time for a mobile station moving away from one base station (e.g., the base station 120 of Figure 2) towards an area with higher levels of interference from another base station (e.g., the base station 122). As can be seen from the plot, the instantaneous CINR can vary quite rapidly.

It makes sense to use a peak throughput estimate that is the average of the peak throughput over the timeframe of interest, i.e. in some scenarios over one or a few seconds. In Figure 8 we show one second averages of the noisy CINR data.

Typically, CINR values reported from different mobile units include some averaging of the CINR in order to reduce the effects of the noise of instantaneous CINR estimates. Of course the amount of averaging taking place may not be readily apparent or known by other than the device manufacture.

Accordingly, to ensure that an appropriate amount of averaging is being performed when estimating the CINR for the purposes of estimating a throughput, in an embodiment several CINR readings per second are taken. A running average CINR value, for example using a simple single pole IIR (exponential) filter

$$CINRavg = \alpha(CINRnew) + (1 - \alpha)(CINRavg)$$

where d is a dimensionless filtering factor ranging between 0 (infinite time averaging) where the average always remains at its initial value and 1 (no averaging).

Generally, when performing this type of averaging, the linear representation of the CINR should be used, not the dB representation. The conversion from CINR in dB to linear is:

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$$CINRlinear = 10^{\frac{CINRdB}{10}}$$

The reverse operation is:

$$CINRdB = 10 * \log_{10} CINRlinear$$

Mobile Device Speed

The mapping between CINR and instantaneous peak throughput also varies with device speed (e.g., in km/hr) as the mobile device moves throughout the area of coverage 124 (see Figure 3).

- If the device speed is unknown then a mapping for a nominal device speed can be used.

- If the device speed is known then a throughput estimate can be made from tables of CINR vs. throughput for two or three device speeds and interpolating the throughputs from the device speeds closest to the measured device speed.

The variation in the mapping based on device speed is generally less than a few percent, so normally a single table using a nominal CINR to throughput mapping is expected to be sufficient.

Device Capabilities

While a CINR value can be mapped to a peak instantaneous throughput, the achievable peak instantaneous throughput that a particular device can achieve may be limited by the device capabilities. In HSPA for example, Table 3 illustrates the following device categories established for HSPA release 6 (from reference (Craigen, 2007)):

HSPA Modem Category	Maximum DL Data Rate
1, 2	1.2 Mbps
3, 4	1.8 Mbps
5, 6	3.6 Mbps
7, 8	7.2 Mbps
9	10.2 Mbps
10	14.4 Mbps
11	0.9 Mbps
12	1.8 Mbps

Table 3 – HSPA device capabilities

At the very least, the instantaneous peak estimation algorithm should make sure that the device capabilities are taken into account so that the peak throughput estimate is capped by the device capabilities.

However, the peak throughput limit for a particular device can manifest itself in different ways. For example a HSDPA device that is capable of receiving only five CDMA codes on the HS-DSCH has a different mapping between CINR and peak throughput when compared to a device capable of receiving all 15 codes (e.g., see Figure 4).

Additionally, the configuration for voice support can also consume codes that could otherwise be used for data, similarly reducing the available peak data bandwidth on the channel regardless of device capability.

Automatic peak throughput vs. CINR learning algorithm

In the previous sections, we have assumed that the mapping between CINR and the throughput is known for a given technology. Often times however, the mapping between a CINR value and a peak throughput may not be readily available for several reasons:

- The mapping may depend on device capabilities. For example, a device may be limited in the number of CDMA codes it can receive

simultaneously. In HSDPA, the peak throughput will change depending on whether or not a mobile device supports MIMO.

- When a mapping is available, it generally refers to the peak physical layer data throughput achievable for a given CINR. However, this peak value includes both user data and any associated control messaging overhead. The peak throughput achievable by a user application will always be lower than the physical layer peak throughout, sometimes by as much as 30%.

- A technology is updated, or a new technology is made available that changes the mapping.

Here we describe how a historical peak-hold throughput estimation mechanism can be modified to automatically learn, over time, the mapping between the CINR measurement at the device and the peak throughout that the device can achieve for each CINR.

In the baseline peak throughput estimation algorithm, a single peak throughput is maintained. In the modified algorithm, a peak throughput is maintained for each CINR value that is seen in the system.

The peak throughput for each CINR can be initialized to zero. When a new peak throughput is determined for a given CINR, the peak throughput of higher CINR values are checked to see if they are less than the peak throughput determined for the lower CINR. If so, then they can be set equal to the peak throughput determined for the lower CINR value. For example, in Table 4 below, a peak value of 1.0 Mbps is measured at a CINR value of 6dB. In the absence of peak throughput measurements at higher CINR levels, it can be assumed that the peak throughput for higher CINR levels is at least as good as the peak throughput value for the actual measurement at 6dB. Thus, the table is updated for higher CINR values based on the single measurement at 6dB. As actual measurements at higher CINR values become available, the table is updated further, as described below.

CINR	Step							
	0	1	2	3	4	5	6	7
-10	0	0	0	0	0	0	0	0
-8	0	0	0	0.2	0.2	0.2	0.2	0.2
-6	0	0	0	0.2	0.2	0.2	0.2	0.2
-4	0	0	0	0.2	0.2	0.2	0.2	0.2
-2	0	0	0	0.2	0.2	0.2	0.2	0.2
0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
4	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
6	0	0.5	1	1	1	1	1	1
8	0	0.5	1	1	1	1	1	1
10	0	0.5	1	1	1	1	1	1
12	0	0.5	1	1	3	3	3	3
14	0	0.5	1	1	3	3	3	3
16	0	0.5	1	1	3	3	3.5	3.5
18	0	0.5	1	1	3	4	4	4
20	0	0.5	1	1	3	4	4	5

Table 4 – CINR vs. peak throughput learning algorithm in action

As more and more peak throughput estimates are established the mapping of CINR to peak throughput is updated.

As an example, Table 4 shows the evolution of a CINR to peak throughput mapping table over time. The CINR values are shown in the first column. Each of the next columns shows the peak throughput table (Mbps units) as it is updated with each new peak throughput estimate corresponding to a particular CINR. The new peak estimate is shown in bold with a highlighted background and the higher CINR peak throughput estimates that are updated based on this estimate are shown in italics with a highlighted background.

At step 1, we assume that the peak throughput estimation algorithm has made its first peak throughput estimate of 0.5Mbps at CINR of 0dB. Since each of the peak estimates for the CINRs greater than 0dB were previously set to zero, they are updated

and set to 0.5Mbps, since the throughput for higher CINRs should be at least as good as the throughput at lower CINRs.

At step 2, the peak estimation algorithm makes a second peak throughput estimate of 1Mbps at a CINR of 6dB. The 6dB CINR entry and all higher CINR entries are updated to 1Mbps.

At step 3, the peak estimation algorithm makes a peak throughput estimate of 0.2Mbps at a CINR of -8dB. The peak throughputs for CINRs from -8dB to -2dB are set to 0.2Mbps, as they were all previously less than 0.2Mbps.

At step 4, the peak estimation algorithm makes a peak throughput estimate of 3Mbps at a CINR of 12dB. The peak throughputs for CINRs from 12dB to 20dB are set to 3Mbps, as they were all previously less than 3Mbps.

At step 5, the peak estimation algorithm makes a peak throughput estimate of 4Mbps at a CINR of 18dB. The peak throughputs for CINRs from 18dB to 20dB are set to 4Mbps, as they were all previously less than 3Mbps.

At step 6, the peak estimation algorithm makes a peak throughput estimate of 3.5Mbps at a CINR of 16dB. Since the peak throughputs of higher CINRs are all greater than 3.5Mbps, only the peak throughput for a CINR of 16dB is updated.

At step 7, the peak estimation algorithm makes a peak throughput estimate of 5Mbps at a CINR of 20dB. Since this is the highest CINR, this is the only one that is updated.

A graph of the peak throughput estimate for each CINR after step 7 is shown in Figure 9. Those skilled in the art will appreciate that the mapping process may operate continually within the wireless communication device 108 (see Figure 1). Updates in the system 100, such as improvements to transmitters in the base station 120 (see Figure 2), for example, may result in a higher data throughput than previously mapped. If the process illustrated in Table 4 operates on a continuous or periodic basis, those changes in the system 100 will be detected and the data in Table 4 can be automatically updated.

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Linear Interpolation

Instead of simply replicating a peak throughput estimate for a given CINR to all higher CINRs that have lower peak throughput estimates, a linear interpolation between the new peak throughput and a higher CINR with a previous peak throughput could be made. The interpolation can also extend to lower CINRs where a previous peak throughput had been made.

Using the same example as above, the evolution of the peak throughput table is shown in Table 5.

CINR	Step							
	0	1	2	3	4	5	6	7
-10	0	0	0	0	0	0	0	0
-8	0	0	0	0.2	0.2	0.2	0.2	0.2
-6	0	0	0	0.275	0.275	0.275	0.275	0.275
-4	0	0	0	0.350	0.35	0.35	0.35	0.35
-2	0	0	0	0.425	0.425	0.425	0.425	0.425
0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2	0	0.5	0.67	0.67	0.67	0.67	0.67	0.67
4	0	0.5	0.83	0.83	0.83	0.83	0.83	0.83
6	0	0.5	1	1	1	1	1	1
8	0	0.5	1	1	1.67	1.67	1.67	1.67
10	0	0.5	1	1	2.33	2.33	2.33	2.33
12	0	0.5	1	1	3	3	3	3
14	0	0.5	1	1	3	3.33	3.33	3.33
16	0	0.5	1	1	3	3.67	3.67	3.67
18	0	0.5	1	1	3	4	4	4
20	0	0.5	1	1	3	4	4	5

Table 5 - Throughput estimation table with linear interpolation

At step 1, since there are no previous throughput estimates made for any CINR, the peak throughput estimate of 0.5Mbps for a CINR of 0dB is filled in as before and extended to all higher CINRs. Note that the peak throughput estimates for lower CINRs are left as-is since there was no previous peak estimate made for lower CINRs.

At step 2 the peak throughout estimate of 1Mbps made for a CINR of 6dB is
extended to all higher CINRs. The peak throughput for the lower CINRs of 2dB and 4dB
are interpolated between the previously established peak throughput of 0.5Mbps at 0dB
CINR and the new estimate of 1Mbps at 6dB CINR.

5   At step 3, the peak throughput estimates for CINRs of -6dB, -4dB and -2dB are
linearly interpolated from the new peak throughput estimate of 0.2Mbps at a CINR of -
8dB and an older peak throughput estimate of 0.5Mbps at 0dB CINR.

At step 4 the peak throughput estimate of 3Mbps at 12dB CINR is replicated to
all higher CINRs and linearly interpolated peak throughput estimates are made for
10   CINRs of 8dB and 10dB.

At step 5 the peak throughput estimate of 4Mbps at 18dB CINR is replicated to
all higher CINRs and linearly interpolated peak throughput estimates are made for
CINRs of 14dB and 16dB.

In the previous example, a peak throughput estimate of 3.5Mbps was made for a
15   CINR of 16dB. In this example, this would be superseded by the interpolated throughput
estimate of 3.67Mbps previously made for this CINR.

Note that we differentiated between peak throughput estimates from the
measured peak throughput estimation and linearly interpolated peak throughput
estimates. The interpolation should only be carried out between estimates made by the
20   measured peak throughput estimation process. Here we assume some method of
measuring the peak channel throughput such as sending a burst of data and measuring
how long it takes to deliver the burst or by some other method such as based on the
latency dynamics of the channel.

This modification to the previous algorithm could be tested empirically to ensure
25   that the interpolated throughput estimates are indeed in line with the actual peaks that
would be measured.

Higher order interpolation

As an alternate to linear interpolation, a higher order interpolating polynomial
30   could be used. For example, Figure 10 shows both a first order (linear) and second
order interpolation between the points (0,0) and (1,1).

The general formula for estimating a throughput, t2 at a CINR, CINR2 when the throughputs t0 and t1 and CINR0 and CINR1 are known is shown in the equation below. For linear interpolation, n=1. For second order interpolation, n=2.

$$t2 = t0 + (t1 - t0)\left(\frac{CINR2 - CINR0}{CINR1 - CINR0}\right)^n$$

5   The updates to the peak throughput estimation table when using a second order interpolation are shown in Table 6.

CINR	Step							
	0	1	2	3	4	5	6	7
-10	0	0	0	0	0	0	0	0
-8	0	0	0	0.2	0.2	0.2	0.2	0.2
-6	0	0	0	0.275	0.275	0.275	0.275	0.275
-4	0	0	0	0.350	0.35	0.35	0.35	0.35
-2	0	0	0	0.425	0.425	0.425	0.425	0.425
0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2	0	0.5	0.67	0.67	0.67	0.67	0.67	0.67
4	0	0.5	0.83	0.83	0.83	0.83	0.83	0.83
6	0	0.5	1	1	1	1	1	1
8	0	0.5	1	1	1.67	1.67	1.67	1.67
10	0	0.5	1	1	2.33	2.33	2.33	2.33
12	0	0.5	1	1	3	3	3	3
14	0	0.5	1	1	3	3.33	3.33	3.33
16	0	0.5	1	1	3	3.67	3.67	3.67
18	0	0.5	1	1	3	4	4	4
20	0	0.5	1	1	3	4	4	5

Table 6 – Throughput estimation table with 2nd order interpolation

A comparison of the throughput vs. CINR table after step 7 for each of the update

10   schemes (replicate only, Linear interpolation and 2nd order interpolation) is shown in Figure 11.

Multiple wireless network types

For some mobile devices there will often be scenarios where the device moves between network types. In these cases there could be several CINR tables maintained corresponding to each separate network type.

For example a terminal could be located on a 3G HSPA network and later travel to a location only served by 2.5G EDGE technology. Since the inherent capabilities of the two types of networks are different, separate CINR-to-peak-throughput tables are learned and maintained on each network type.

In order to determine which lookup table to use the mobile device would need a reporting method to indicate the currently serving network type. It is understood that this type of reporting is a standard feature of the application programming interfaces in most commercial handsets.

Mobile Wireless Technologies Summary

Table 7 shows a list of the most common packet switched wireless technologies and their peak data rate capabilities. These are the technologies supported by modern smartphones.

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Technology	Family	Data Rates
GPRS	3GPP	56kbps typical 114kbps max
EDGE	3GPP	180kbps typical 236.8kbps peak (4 timeslots) 473.6kbps peak (8 timelsots)
UMTS (W-CDMA)	3GPP	2Mbps peak
HSDPA	3GPP	1.8 - 14.4Mbps peak 3.5 Mbps/sector typical
HSPA+ (Release 7)	3GPP	21-28 Mbps peak (2x2 MIMO) 1.8 – 14.4Mbps peak (2x1 SIMO) 6.2 Mbps/sector typical
LTE	3GPP	>100Mbps
CDMA-2000	3GPP2	144kbps peak
CDMA2000 1x RTT	3GPP2	307.2 kbps peak 125 kbps typical
EV-DO 1x Rev. 0	3GPP2	2.45 Mbps peak, 750kbps typical
EV-DO 1x Rev. A	3GPP2	3.1 Mbps
EV-DO Rev. B	3GPP2	4.9 Mbps/carrier

Table 7 – Deployed Wireless Data Technologies

Thus, one can appreciate that peak throughput values can be measured in a variety of different manners and associated with a particular data throughput rate. The data throughput rate is dependent on the quality of the wireless communication link 112 (see Figure 1). However, the quality of the wireless communication link 112 is dependent upon a number of factors discussed above. In addition, the actual type of the wireless communication device 108 may affect the data throughput. That is, some devices are simply faster than other devices and thus have a greater data throughput for a given quality value of the wireless communication link 112. For this reason, in one embodiment, the system 100 stores the table or tables discussed above in a storage location within the wireless communication device 108 itself. The data may be conveniently stored as a data look-up table. However, any form of suitable data storage structure may be used to satisfactorily implement the system 100. The system 100 is not limited by any particular form of data storage. In one embodiment, the wireless communication device 108 may store data tables for multiple base stations, such as the base stations 120-122 in Figure 2. This may be especially useful in situations where the

overall communication has base stations that are not identical, and thus have different data throughput values. For example, the communication link 138 coupling the base station 120 to the BSC 136 may comprise multiple T1 backhaul lines. In contrast, the communication link 140 coupling the base station 122 to the BSC 136 may have only a single T1 backhaul line. Those skilled in the art can appreciate that the base station 120 may have significantly greater data throughput rates because of decreased backhaul congestion on the communication link 138. In this circumstance, the wireless communication device 108 may have data tables for both the base stations 120 and 122 so as to distinguish between poor radio quality links and network congestion separately for each base station.

Those skilled in the art will appreciate that only a single data table may be applicable for all base stations if the telecommunication network uses identical base stations and identical backhaul communication links.

In yet another variation, the wireless communication device 108 may store different data tables for different sectors of a cell site. For example, the sector 130 in Figure 3 may have a lower data transmission throughput rate than, by way of example, the sector 126. Thus, the wireless communication device 108 can retrieve the appropriate data based on the particular sector with which the wireless communication device is communicating. If all sectors have identical capabilities throughout the wireless communication system, the wireless communication device 108 need only store a single table that is applicable to all sectors.

In yet another alternative embodiment, the data table discussed above may be stored remotely from the wireless communication device 108 and downloaded at the start of a communication session to download a data file. For example, the data tables discussed above can be downloaded to the wireless communication device 108 via the RAN 110 illustrated in Figure 1. For example, at the start of a data transfer session, the data file is stored in the data source 104. Just prior to the initiation of the data file download, the appropriate data tables for the currently serving base station (and sectors), as well as data tables for nearby base stations (and sectors) may be downloaded to the wireless communication device 108. In this manner, a wireless communication device 108 receives the current data for the nearby base stations. As

noted above, data transfer rates may be dependent. Thus, the system 100 can provide the appropriate data tables to the wireless communication device 108 based on the identification of the type of wireless communication device to which the data file will be transferred.

5   As discussed above, the wireless communication device 108 uses the data table to determine the expected peak data throughput based on the current measured value of the CINR. For example, using the data from Table 4 (Step 7), the wireless communication device measures the current CINR value if, by way of example, the CINR value is 8dB, the expected peak throughput rate is 1.0Mbps. If the actual data

10   throughput rate is lower than this value, the wireless communication device can send a message to the data source 204 via the RAN 110 indicating that it has detected congestion. In response to network congestion, the system 100 can cause the data source 104 to slow down or even temporarily suspend data transfer so as to avoid the undesirable side effects of network congestion. This advantageously allows the system

15   100 to differentiate between low transfer rates caused by poor quality of the wireless communication link 112 (see Figure 1) versus low transfer rates caused by network congestion. If the low transfer rate is caused by poor quality of the wireless communication link 112, the wireless communication device 108 can also send a message to the data source 104 via the RAN 110 indicating that the low transfer rate is

20   caused by poor coverage rather than network congestion.

Those skilled in the art will appreciate that the actual data throughput rate may momentarily drop below the expected data throughput rate. To avoid unnecessary reporting, the system 100 may further add a time duration threshold prior to sending a congestion detection message to the data source 104. For example, the system may

25   impose a time duration requirement that requires that the actual data throughput rate is below the expected peak throughput rate for a pre-determined period of time. In one example, the system 100 could require that the actual data throughput rate is less than the expected peak throughput rate for at least one second before it sends a congestion detection message to the data source 104. In yet another variation, the system may

30   require that the actual data throughput rate be less than the expected peak throughput rate by a threshold amount. For example, if the expected throughput rate is 1.0 Mbps

and the actual data throughput rate is 995Kbps, one may consider that the wireless
communication link 112 is operating essentially at its peak channel capacity. Again, to
avoid unnecessary reporting of congestion, the system may require that the actual data
throughput rate be less than the expected peak throughput rate by a pre-determined
5   threshold amount. The threshold amount may be stated in absolute terms (e.g., the
actual data throughput rate is less than the expected peak throughput rate by 25Kbps)
or as a percentage of the expected peak throughput rate (e.g., the actual data
throughput rate is less than 90% of the expected peak throughput rate). In yet another
embodiment, the system 100 could use a combination of the time duration threshold
10   and a drop in the actual throughput rate below a threshold value.

        In the process described above, the wireless communication device
autonomously discovers the peak channel capacity for various levels of signal quality
(e.g., CINR) and automatically completes the table, such as Table 4, in an iterative
process. Those skilled in the art will appreciate that this iterative process can be a
15   continuous and on-going process. While Table 4 illustrates only 7 steps from the
starting point where the data table is empty, the process can continue until each of the
CINR values has an actual measurement. Furthermore, as time goes on, aspects of the
system 100 may change thus making the data obsolete. For example, changes to the
RAN 110 may result in an improvement of the base station 122. Because the base
20   station 122 may now have a greater throughput rate, the data tables may be altered to
reflect the fact that a greater throughput may be available for a given CINR value.

        In yet another embodiment, the data tables for a particular wireless
communication device may be prepopulated, thus eliminating the need for a multi-step
process illustrated in the data tables above. For example, rather than start with the data
25   tables having a value of zero for all quality levels of the wireless communication link
112, the system 100 may preload the data table and download it to the wireless
communication device 108 via the RAN 110. For example, the data of Table 4, Step 7
can be downloaded to the wireless communication device 108 for the particular base
station and/or sector with which the wireless communication device is currently
30   communicating. Thus, the wireless communication device begins with a prepopulated
data table that reasonably reflects the expected data throughput rates for a given quality

value of the wireless communication link 112 (see Figure 1). The wireless communication device 108 can update the prepopulated data table as discussed above to reflect current system conditions. As noted above, the expected peak data throughput rates may vary based on the type of the wireless communication device 108.

5 Thus, the system 100 must prepopulate the data table with data appropriately selected for the type of wireless communication device 108.

The examples presented above relate to network congestion on the downlink. That is, network congestion while transferring a data file from the data source 104 (see Figure 1) coupled to the network 106 and downloaded via the downlink to the wireless

10 communication device 108. However, the principles described herein are equally applicable to the uplink. That is, the wireless communication device 108 may wish to upload a file, such as a video or multi-media file, to the network 102 via the RAN 110. The general methodology described herein is applicable to both the downlink and the uplink. The added challenge with the uplink is that measurement of the quality of the

15 wireless communication link 112 is more direct because the wireless communication device 108 cannot directly determine the quality of the radio signal received by the base station (e.g., the base station 120 in Figure 2). However, there are indirect methods that can be used to determine the quality of the wireless communication link 112. For example, the transmit power and/or the MCS that the base station 120 commands the

20 wireless communication device 108 to use are indicators of the quality of the wireless communication link 112. A higher transmit power on the uplink or a more robust MCS tends to indicate a lower quality for the wireless communication link 112. Thus, the wireless communication link 112 would have a lower data throughput capacity. Additionally, the base station 120 can be configured to transmit a signal quality indicator

25 back to the wireless communication device 108 for its determination of and distinction between congestion issues versus radio coverage quality. Furthermore, from a practical standpoint, the wireless communication device 108 can be configured to assume that the uplink and downlink channels are roughly symmetrical in quality and simple use the downlink quality values for the wireless communication link 112 as the

30 indication of uplink quality. The wireless communication device 108 can construct an uplink table indicating quality of the wireless communication link 112 uplink versus

expected data throughput in a manner similar to that discussed above with respect to the examples of the downlink quality. Those skilled in the art will appreciate that in the uplink case, the terms "server" and "client" end points are essentially reversed. In this example, it is the wireless communication device 108 that would have to throttle back its

5   data rate in the presence of congestion while in the downlink example, it is the data source 104 (see Figure 1) that throttles its data delivery rate to avoid congestion.

Thus, the system 100 provides a useful technique for distinguishing between low data transfer rates caused by poor quality of the wireless communication link 112 (see Figure 1) versus network congestion. The network need only slow down the data

10   transfer rate if network congestion exists. The system allows each wireless communication device to autonomously detect the peak channel capacity and to iteratively populate a data table that may be unique to the wireless communication device, the base station, base station sector, or the like.

The foregoing described embodiments depict different components contained

15   within, or connected with, different other components. It is to be understood that such depicted architectures are merely exemplary, and that in fact many other architectures can be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality is achieved. Hence, any two components herein

20   combined to achieve a particular functionality can be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated can also be viewed as being "operably connected", or "operably coupled", to each other to achieve the desired functionality.

25   While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that, based upon the teachings herein, changes and modifications may be made without departing from this invention and its broader aspects and, therefore, the appended claims are to encompass within their scope all such changes and modifications as are within the true spirit and scope of

30   this invention. Furthermore, it is to be understood that the invention is solely defined by the appended claims. It will be understood by those within the art that, in general, terms

used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited

5   to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations.

10   However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to inventions containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should

15   typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation *is* explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean *at least* the recited number (e.g., the bare recitation of "two recitations," without other modifiers,

20   typically means *at least* two recitations, or *two or more* recitations).

Accordingly, the invention is not limited except as by the appended claims.

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CLAIMS

The invention claimed is:

1.   A method for use in a communication network comprising:

determining a quality value representing a signal quality in radio link between a base station and a wireless communication device;

determining a data throughput value in the radio link for the determined signal quality value;

storing the data throughput value in association with the quality value; and

in a subsequent communication at a later time:

determining a current quality value representing the current signal quality in the wireless communication device;

determining an expected data throughput value by retrieving the stored data throughput value associated with the stored signal quality value equal to the current quality value;

determining a current data throughput value;

detecting congestion in the communication network if the current data throughput value is less than the expected data throughput value.

2.   The method of claim 1, further comprising repeating the determining a quality value for a plurality of different quality values, determining a data throughput value in the radio link for each of the plurality of different quality values, and storing the data throughput value associated with each of the respective plurality of quality values to thereby provide a range of data throughput values associated with a range of quality values.

3.   The system of claim 1 wherein determining the quality value representing the signal quality comprises measuring one or a combination of one or more signal quality values selected from a group of signal quality values comprising a signal

strength value, a carrier to interference plus noise value, and a channel quality indicator value.

4.   The method of claim 1 wherein the wireless communication device communicates with a plurality of different base stations and wherein determining a quality value, determining a data throughput value, and storing the data throughput value in association with the quality value is performed for each of the plurality of base stations.

5.   The method of claim 4 wherein in the subsequent communication is with a selected one of the plurality of base stations and the expected data throughput value is determined by retrieving the stored data throughput value associated with the stored signal quality value equal to the current quality value for the selected base station.

6.   The method of claim 1 wherein the wireless communication device communicates with a plurality of different sectors of the base station and wherein determining a quality value, determining a data throughput value, and storing the data throughput value in association with the quality value is performed for each of the plurality of base station sectors.

7.   The method of claim 6 wherein in the subsequent communication is with a selected one of the plurality of base station sectors and the expected data throughput value is determined by retrieving the stored data throughput value associated with the stored signal quality value equal to the current quality value for the selected base station sector.

8.   The method of claim 1 wherein storing the data throughput value in association with the quality value comprises storing the data in a storage location of the wireless communication device.

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9.   The method of claim 1 wherein storing the data throughput value in association with the quality value comprises storing the data in a storage location of the communication network and remote from the wireless communication device.

10.   The method of claim 9 wherein retrieving the stored data throughput value comprises retrieving the stored data throughput value from the storage location of the communication network and transmitting the retrieved data throughput value to the wireless communication device via the radio link between the base station and the wireless communication device.

11.   The method of claim 1 wherein detecting congestion in the communication network comprises determining if the current data throughput value is less than the expected data throughput value by a predetermined amount.

12.   The method of claim 1 wherein detecting congestion in the communication network comprises determining if the current data throughput value is less than the expected data throughput value for a predetermined amount of time.

13.   A wireless communication device configured for communication in a communication network, comprising:
        a transceiver configured to establish a wireless communication link with a base station;
        a controller configured to determine a quality value related to a quality of the wireless communication link and to determine a peak channel capacity of the wireless communication link for the determined quality value; and
        a data storage structure configured to receive and store the peak channel capacity in association with the determined quality value, the controller being further configured to subsequently determine a current data throughput of the wireless communication link for the determined quality value and generating an indication that congestion is detected in the communication network if the current data throughput is less than the peak channel capacity for the determined quality value.

14. The wireless communication device of claim 13 wherein the controller is further configured to generate the indication that congestion is detected if the current data throughput is less than the peak channel capacity for the determined quality value by a predetermined amount.

15. The wireless communication device of claim 13 wherein the controller is further configured to generate the indication that congestion is detected if the current data throughput is less than the peak channel capacity for the determined quality value for a predetermined amount of time.

16. The wireless communication device of claim 13 wherein the controller is further configured to determine a plurality of quality values related to a quality of the wireless communication link in different conditions and determine a peak channel capacity of the wireless communication link for each of the plurality of determined quality values.

17. The wireless communication device of claim 13 wherein the wireless communication device communicates with a plurality of different base stations and wherein the controller is configured to determine a quality value and the peak channel capacity for each of the plurality of base stations.

18. The wireless communication device of claim 13 wherein the wireless communication device communicates with a plurality of different sectors of the base station and wherein the controller is configured to determine a quality value and the peak channel capacity for each of the plurality of base station sectors.
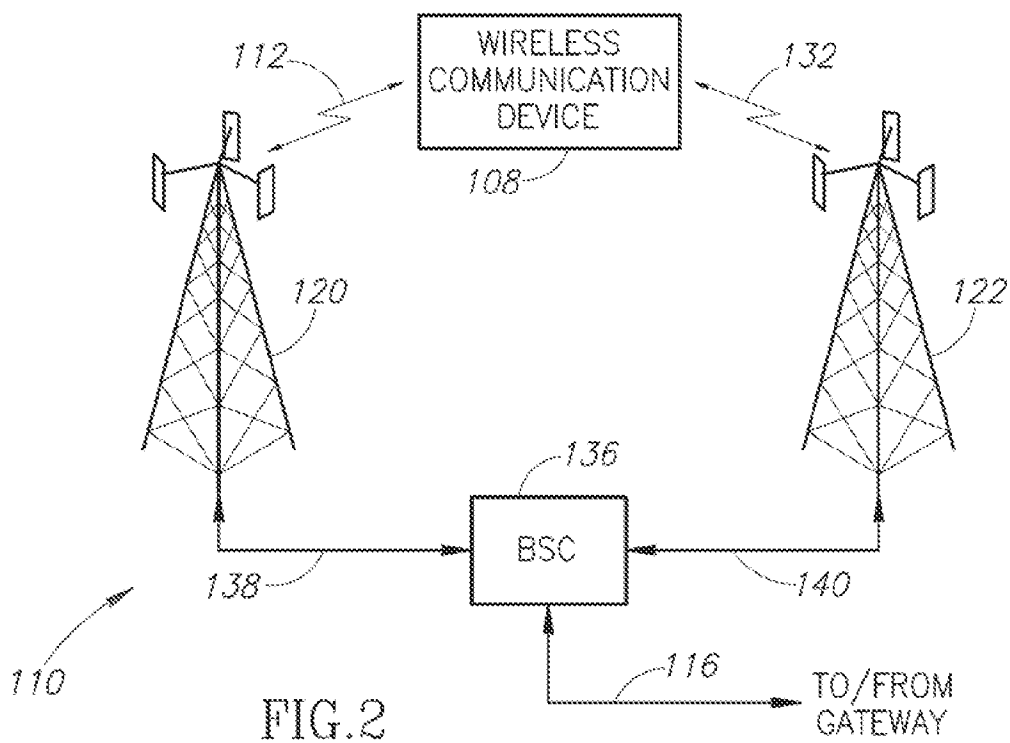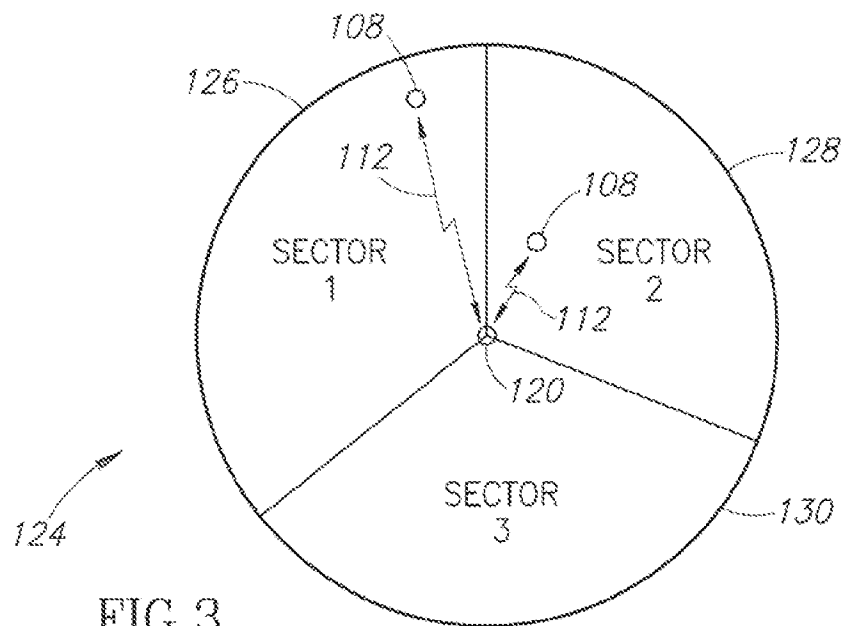
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FIG.1

FIG.2

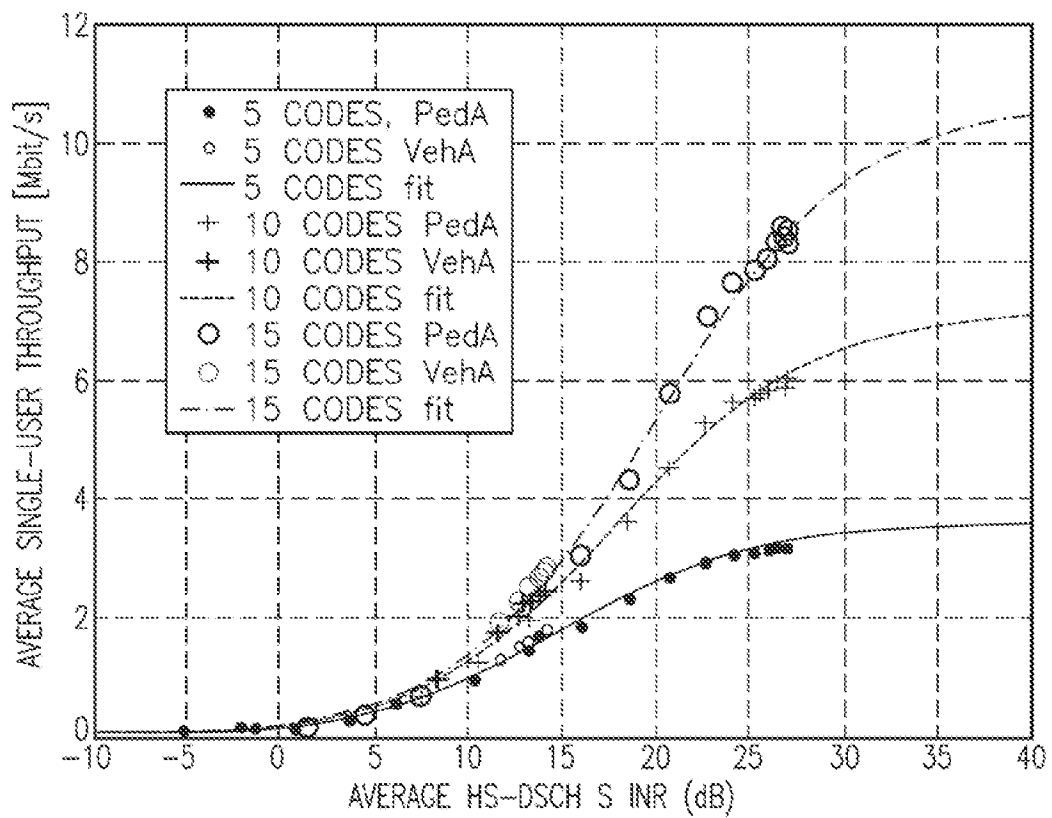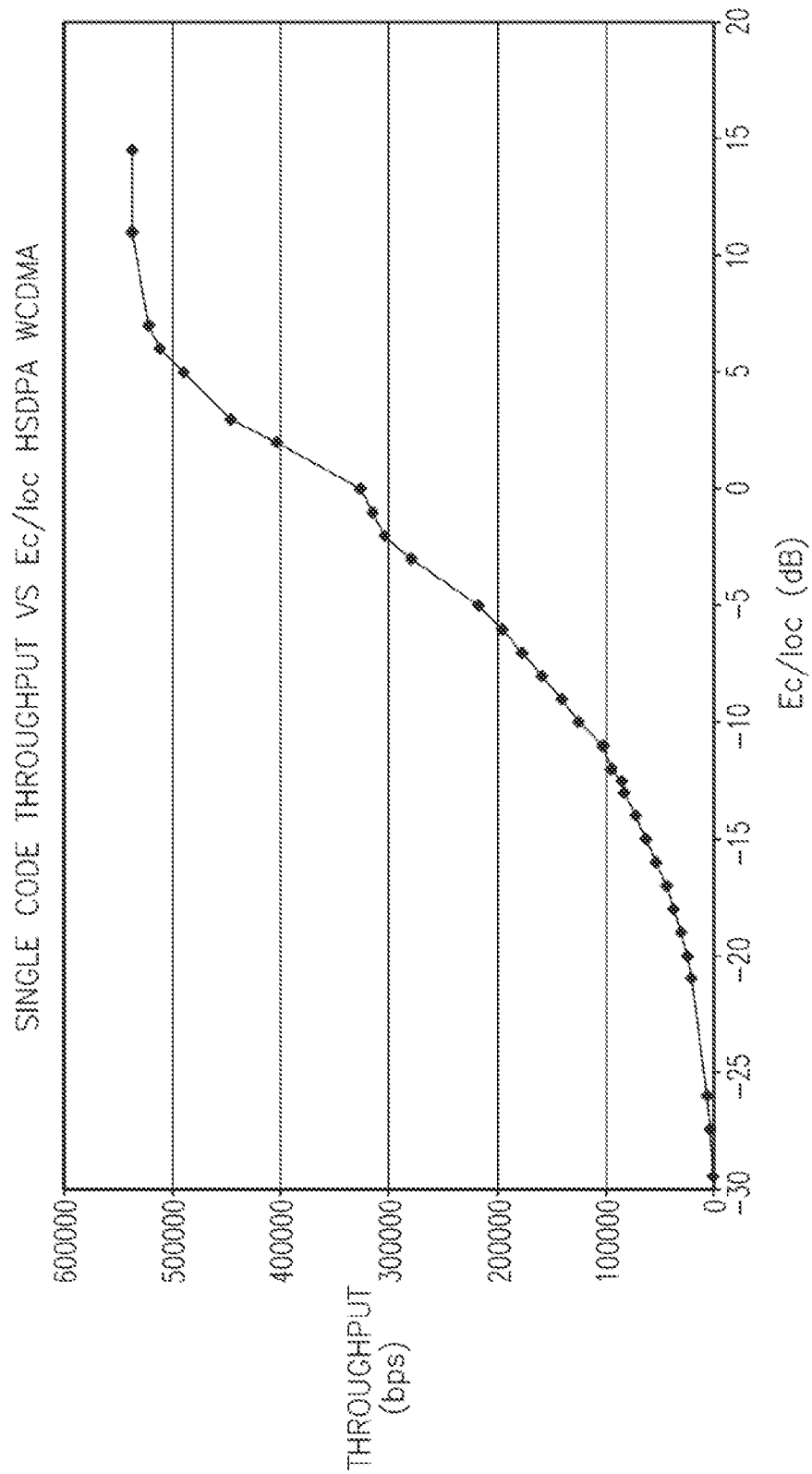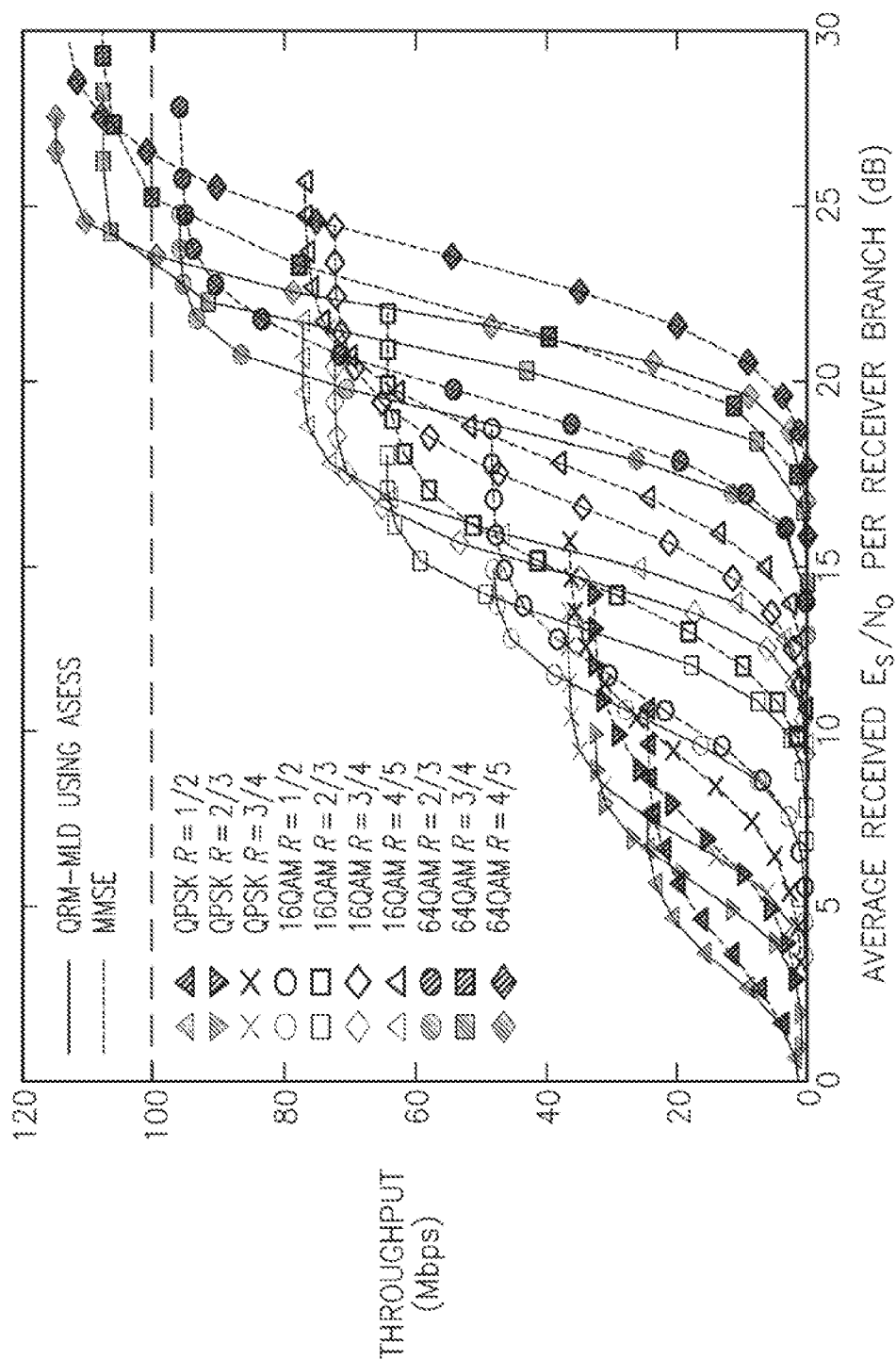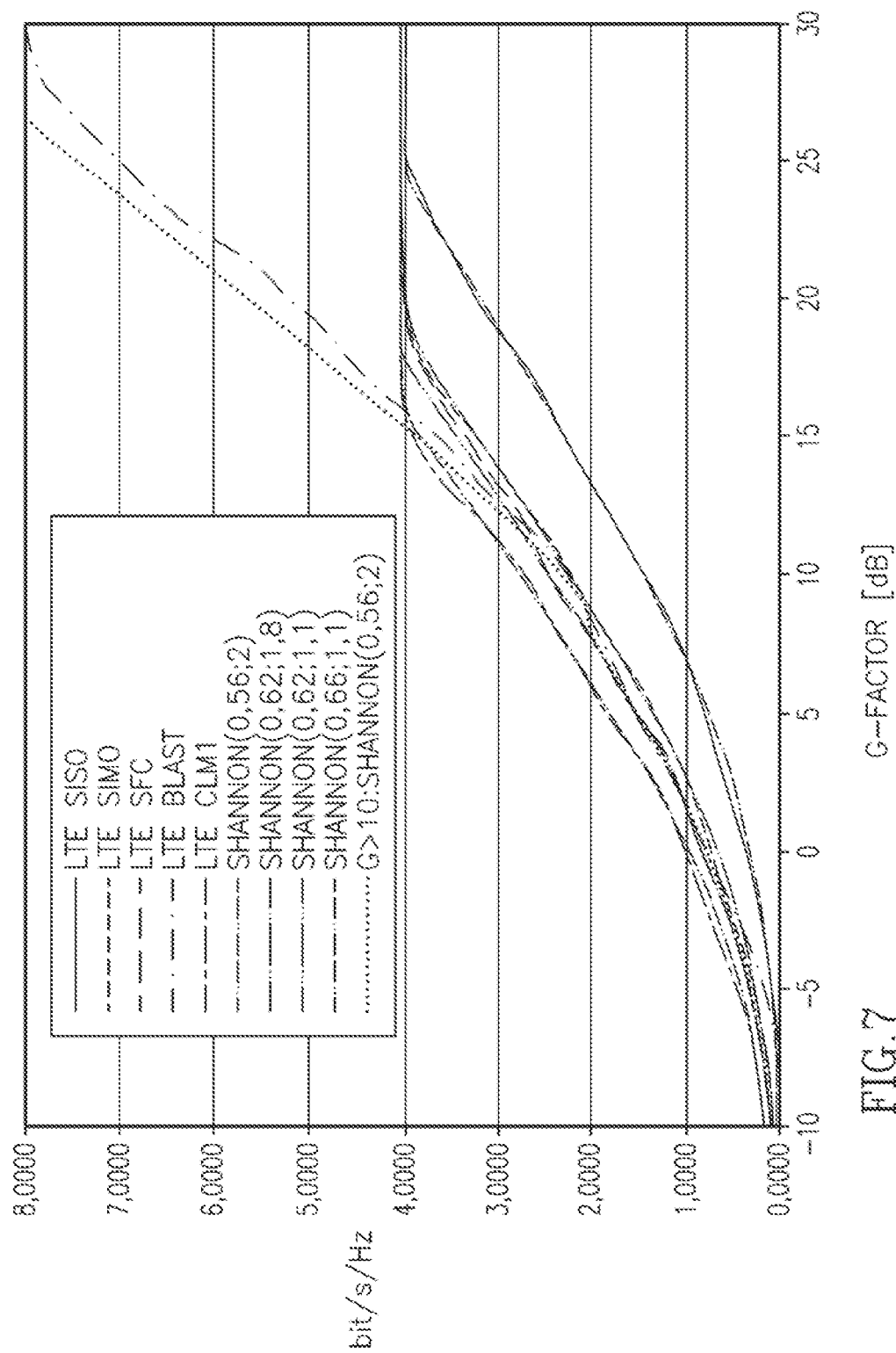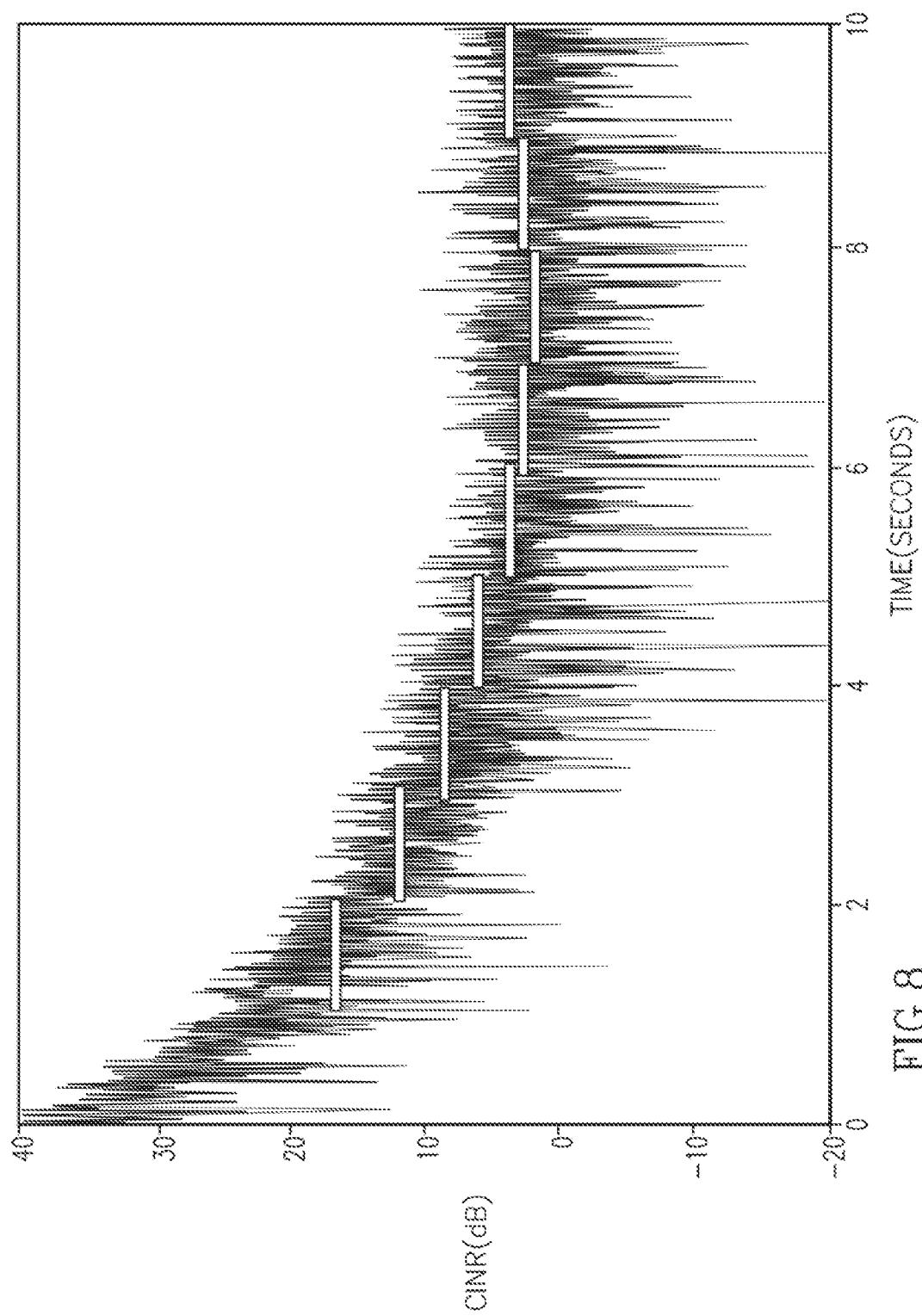FIG.3

FIG.4

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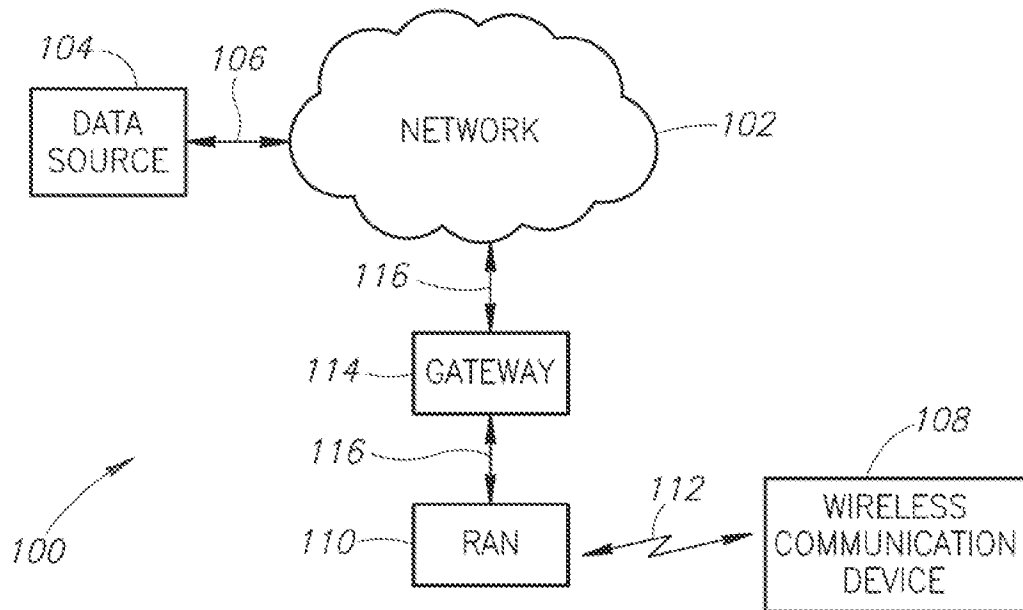
FIG.5

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FIG.6

FIG. 7

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FIG.8

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FIG.9

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FIG.10

FIG.11