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Link Capacity Estimation for Devices in Idle State

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LINK CAPACITY ESTIMATION FOR DEVICES IN IDLE STATE

Abstract

In order to estimate throughput between a user device and a radio access network (RAN), a modem of the user device may estimate the link capacity of the link between the user device and the RAN. When the user device is in a connected state, the modem can determine link capacity estimation (LCE) values directly, based on signal strength parameter values measured by the modem from signals received by the user device from a given RAN. In order to estimate the link capacity for a user device that is in an idle mode, the modem of the user device may maintain, in memory, one or more look-up tables (LUTs) in which historical, aggregate LCE values are stored and organized into various buckets according to signal strength parameter type and signal strength measurement value range. The modem may obtain signal strength parameter measurements while the user device is in a connected state, calculate an LCE value for each signal strength parameter measurement, and update a moving average or weighted average of LCE values for a corresponding bucket. When the user device enters the idle mode from the connected mode, the modem receives signal strength parameter measurements (e.g., from paging signals received by the user device from a RAN), determines new LCE values (one for each signal strength parameter type) based on those signal strength parameter measurements, identifies the buckets to which each new LCE value correspond, calculates an average of the historical, aggregate LCE values for each identified bucket, then uses the average of the historical, aggregate LCE values to estimate what the throughput will be between the RAN and the user device when the user device transitions back to the connected state.

Background

Mobile applications, such as those used for video streaming or game streaming, can be sensitive to data speed and therefore tend to employ encoding algorithms, referred to as codecs, for encoding the data stream, wherein the codecs are optimized based upon available throughput. Some user devices select the codec for a data stream based on a link capacity estimation (LCE) value for a link over which the data is to be communicated. Current mechanisms of calculating and reporting LCE do not accurately represent the link capacity while the user device for which LCE value is being calculated is in an idle state, such as the New Radio – Radio Resource Control (NR-RRC) idle state or the Long Term Evolution – Radio Resource Control (LTE-RRC) idle state.

Description

Herein, algorithms are disclosed for accurately estimating link capacity between a user device and a RAN while the user device is in an idle state, thereby improving the performance of bandwidth-sensitive applications and associated user experiences. A mobile user device executing bandwidth-sensitive applications such as video or game streaming applications may send and receive data via a mobile data network (e.g., 5G or LTE). FIG. 1 shows an example of a high-level system architecture, illustrating data flow between the modem and operating system of a user device, where the modem sends and receives data via such a mobile data network.

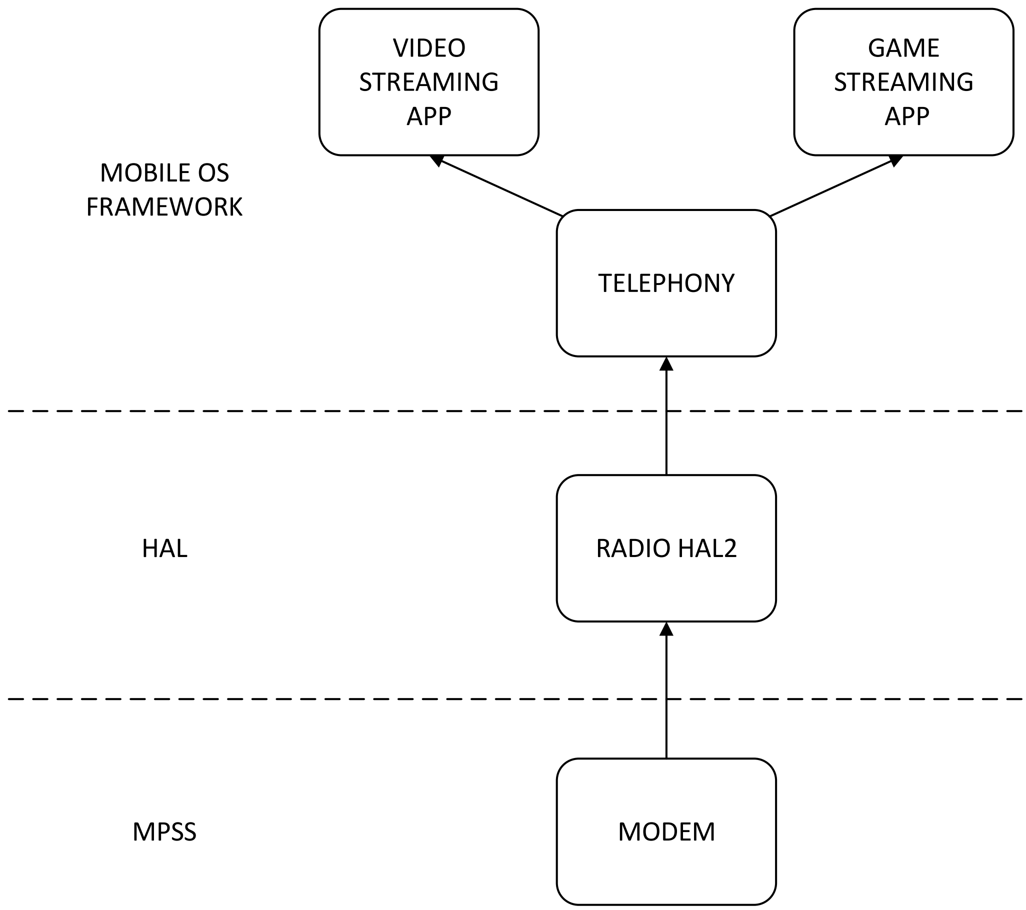

FIG. 1

As shown, video and game streaming applications can be implemented in the mobile operating system (OS) framework in connection with a telephony framework. A radio interface, denoted as ‘RADIO HAL2’, may be implemented in the hardware abstraction layer (HAL). The modem may be implemented using modem peripheral subsystem software (MPSS). During operation of the user device, signals sent by a RAN may be received by the modem, which may process the signals (e.g., to measure signal strength parameters) before sending the signals to a corresponding application via the radio interface and telephony framework.

When communicating with a RAN (e.g., a base station) over an established link, a user device can operate in a connected state (e.g., the NR-RRC connected state or LTE-RRC connected state). In some instances, the user device may transition into an idle state (e.g., the

NR-RRC idle state or LTE-RRC idle state) in which the user device powers down its transceiver during defined time intervals to save power, and only communicates with the network device to receive paging signals or to establish an active connection with the RAN.

While a user device is in a connected state, a modem of the user device may measure signal strength parameters for signals received by the modem from the RAN (more specifically, the base station) to which the user device is connected. For example, the signal strength parameters may include reference signal received power (RSRP), reference signal received quality (RSRQ), and reference signal signal to noise ratio (RSSNR). For a given network cell, the modem may “bucketize” each signal strength parameter measured for signals received by the modem from that RAN, and may calculate and store historical, aggregate LCE values for each bucket. For example, a predetermined number of buckets (e.g., about nine buckets) may be defined for each signal strength parameter, with each bucket representing a range of values of the corresponding signal strength parameter. When the modem calculates a new LCE value for a link between the user device and a RAN based on a measured signal strength parameter of a given signal strength parameter type, the new LCE value is use to update the historical, aggregate LCE value of a corresponding bucket associated with the RAN, the given signal strength parameter type, and the value of the signal strength parameter used to calculate the new LCE value. For example, RSRP values may be assigned to one of the following buckets (values are in dBm): [> -70], [-70 - -80], [-80 - -90], [-90 - -100], [-100 - -110], [-110 - -120], [-120 - -130], [-130 - -140], [< -140].

In some implementations, the modem maintains a respective lookup table (LUT) for each RAN that the user device has communicated with, where each LUT includes the RSRP, RSRQ, and RSSNR buckets and corresponding historical, aggregate LCE values for each bucket. In other implementations, the modem maintains LUTs that include the RSRP, RSQR, and RSSNR buckets and corresponding historical, aggregate LCE values for a predetermined number (e.g., about nine or ten) of the RANs that are most-used by the user device (i.e., the RANs with which the user device most frequently engages in communication), and separately maintains a global LUT that includes the RSRP, RSQR, and RSSNR buckets for any other RANs with which the user device has communicated. The use of a global LUT in the latter bucketing approach may be useful in user devices having memory constraints, which may not be able to create and maintain respectively unique LUTs for all cell IDs (e.g., for all RANs to which the user device has connected) due to those constraints.

In either bucketing approach, the modem calculates and stores an average LCE value (i.e., the historical, aggregate LCE value) and a count for each bucket. The count for a given bucket represents the number of signal strength parameter values measured by the modem that fall within the range defined for that bucket and that correspond to signals received from the RAN associated with that bucket. The modem may only need to store the historical, aggregate LCE value and count for each bucket, without needing to store each signal strength parameter value measurement associated with each bucket, which may reduce processing and storage overhead. A new LCE value may be calculated for the bucket each time a new signal strength parameter value is measured that corresponds to the bucket and the associated RAN. In one implementation, the new LCE may be calculated by the modem by accessing a look-up table that defines relationships between signal strength parameters (i.e., RSRP, RSRQ, and/or RSSNR values) and available link capacity. In another implementation, the new LCE value may be calculated by the modem by executing one or more algorithms that define relationships between RSRP, RSRQ, and/or the RSSNR and available link capacity.

In some implementations, the modem may store and maintain an average LCE value as the historical, aggregate LCE value for a given bucket, which may be a weighted average LCE value for that bucket that is updated each time a new LCE value is calculated for a newly measured signal strength parameter value that is identified as corresponding to that bucket. An example of calculating the weighted average LCE value for an RSRP bucket given a new LCE value in accordance with such an implementation is provided in EQ. 1:

$$LTElookupTable.rsrp\_buckets[rsrp\_level].lce = ((LTElookupTable.rsrp\_buckets[rsrp\_level].count * LTElookupTable.rsrp\_buckets[rsrp\_level].lce) + newLCE)/ (count + 1)$$ **EQ. 1**

Here, $LTElookupTable.rsrp\_buckets[rsrp\_level].lce$ is defined as the average LCE value for an RSRP bucket, $LTElookupTable.rsrp\_buckets[rsrp\_level].count$ is defined as the number of RSRP measurements within the RSRP bucket's range made by the modem based on signals received from the RAN associated with the RSRP bucket, $rsrp\_level$ denotes the particular RSRP bucket being considered, and $newLCE$ represents a new LCE value that has been calculated based on a new RSRP measurement that falls within the range of values associated with the RSRP bucket. Here, when calculating the new average LCE value for the RSRP bucket, the previous average LCE value for the RSRP bucket is weighted according to the historical RSRP measurement "count" associated with the RSRP bucket, while the new LCE value is weighted by a single count. An example of incrementing the count for the RSRP bucket is provided in EQ. 2:

$$LTE\ lookupTable.rsrp\_buckets[rsrp\_level].count = LTElookupTable.rsrp\_buckets[rsrp\_level].count + 1$$ **EQ. 2**

The average LCE value and count calculations provided in EQs. 1 and 2 are also applicable to other signal strength parameters, such as RSRQ and RSSNR.

In some implementations, instead of taking a dynamic moving average of the LCE values for each bucket (e.g., in which the weight of the previous average LCE value for a given bucket increases as the count for that bucket increases), the modem calculates a predefined (i.e., static) weighted average of the LCE value for each bucket as the historical, aggregate LCE value for that bucket. In one example of how to employ such static weighted averaging when updating the average LCE value for a bucket, the previous average LCE value for the bucket may always be given a weight of X, and a new LCE value may always be given a weight of 1-X, where X is a predetermined value between 0 and 1.

If the user device transitions to an idle state, the modem of the user device can calculate the LCE for the idle user device and a given RAN, given a single set of signal strength parameter values ("idle signal strength parameter values") measured by the modem from signals received by the user device from the RAN while in the idle state (e.g., obtained from paging signals sent by the RAN). The modem may identify signal strength parameter buckets associated with the RAN that correspond to the idle signal strength parameter values, and may estimate the link capacity between the user device and the RAN based on the historical, aggregate LCEs of the identified signal strength parameter buckets. In the example of EQ. 3, an estimated link capacity between a given RAN and an idle user device is taken as the average of an historical, aggregate LCE for an RSRP bucket; an historical, aggregate LCE for an RSRQ bucket; and an historical, aggregate LCE for an RSSNR bucket associated with the RAN and maintained by the modem of the idle user device:

$$(LTElookupTable.rsrp\_buckets[rsrp\_level].lce + LTElookupTable.rsrq\_buckets[rsrq\_level].lce + LTElookupTable.rssnr\_buckets[rssnr\_level].lce)/3 \qquad \textbf{EQ. 3}$$

Here, the RSRP, RSRQ, and RSSNR buckets are those having defined ranges that include the respective RSRP, RSRQ, and RSSNR values measured from a signal (e.g., paging signal) received by the modem from the RAN while the user device is in the idle state.

In the example of EQ. 4, an estimated link capacity between the idle user device and the RAN is instead taken as the minimum of the historical, aggregate LCE value for the RSRP bucket, the historical, aggregate LCE value for the RSRQ bucket, and the historical, aggregate LCE value for the RSSNR bucket:

$$MIN(LTElookupTable.rsrp\_buckets[rsrp\_level].lce, LTElookupTable.rsrq\_buckets[rsrq\_level].lce, LTElookupTable.rssnr\_buckets[rssnr\_level].lce) \qquad \textbf{EQ. 4}$$

In the Example of EQ. 5, an estimated link capacity between the idle user device and the RAN is taken as the maximum of the historical, aggregate LCE for the RSRP bucket, the historical, aggregate LCE for the RSRQ bucket, and the historical, aggregate LCE for the RSSNR bucket:

$$MAX(LTElookupTable.rsrp\_buckets[rsrp\_level].lce, LTElookupTable.rsrq\_buckets[rsrq\_level].lce, LTElookupTable.rssnr\_buckets[rssnr\_level].lce) \qquad \textbf{EQ. 5}$$

When considering which approach provides the most accurate estimation of link capacity between a modem and a RAN, using the minimum historical, aggregate LCE value may result in an estimated link capacity that is much lower than the actual link capacity of the link between the modem and the RAN, using the maximum historical, aggregate LCE value may result in an estimated link capacity that is much higher than the actual link capacity of the link between the modem and the RAN, while using the average of the historical, aggregate LCE values may avoid excessive overshoot or undershoot of the actual link capacity of the link between the modem and the RAN.

While examples provided above involve LCE calculations that are performed at the modem of a user device, it should be understood that the CPU and primary operating system of the user device could instead be used to perform such LCE calculations. However, generally, it may be beneficial to execute the algorithms for calculating the LCE for a given link at the modem of the user device, rather than at the CPU and primary operating system of the user device, in that the modem provides more accurate signal strength parameter measurements (even when the screen of the user device is off) and more accurate LCE data. Further, performing LCE calculations using the CPU and operating system of the user device when the user device is in an idle state would require the CPU to “wake-up” to perform the calculation, and could therefore be resource inefficient if the CPU would have otherwise been in an idle state.

References

Method and apparatus for estimating an achievable link throughput based on assistance information, U.S. Patent Pub. No. 20140334318, filed April 25, 2014, the entirety of which is hereby incorporated by reference.

Method of Finding a Physical Location of a Mobile Telephone at a Given Time, U.S. Patent Pub. No. 20100159957, filed August 9, 2006, the entirety of which is hereby incorporated by reference.

A measurement-based approach to modeling link capacity in 802.11-based wireless networks Kashyap et al., published September 9-14, 2007, the entirety of which is hereby incorporated by reference.