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A METHOD OF REDUCING THE CHANCES OF SERVICE INTERRUPTION DUE TO RADIO LINK FAILURE

Abstract

The operation of a user equipment is constrained during a prohibit time interval to reduce the likelihood of service interruptions due to a radio link failure. The constraints include preventing the user equipment from camping or connecting to the network via the cell during the prohibit time interval. The duration of the prohibit time interval is modified based on whether the radio link failure problem persisted (or reoccurred) following the prohibit time interval.

Background

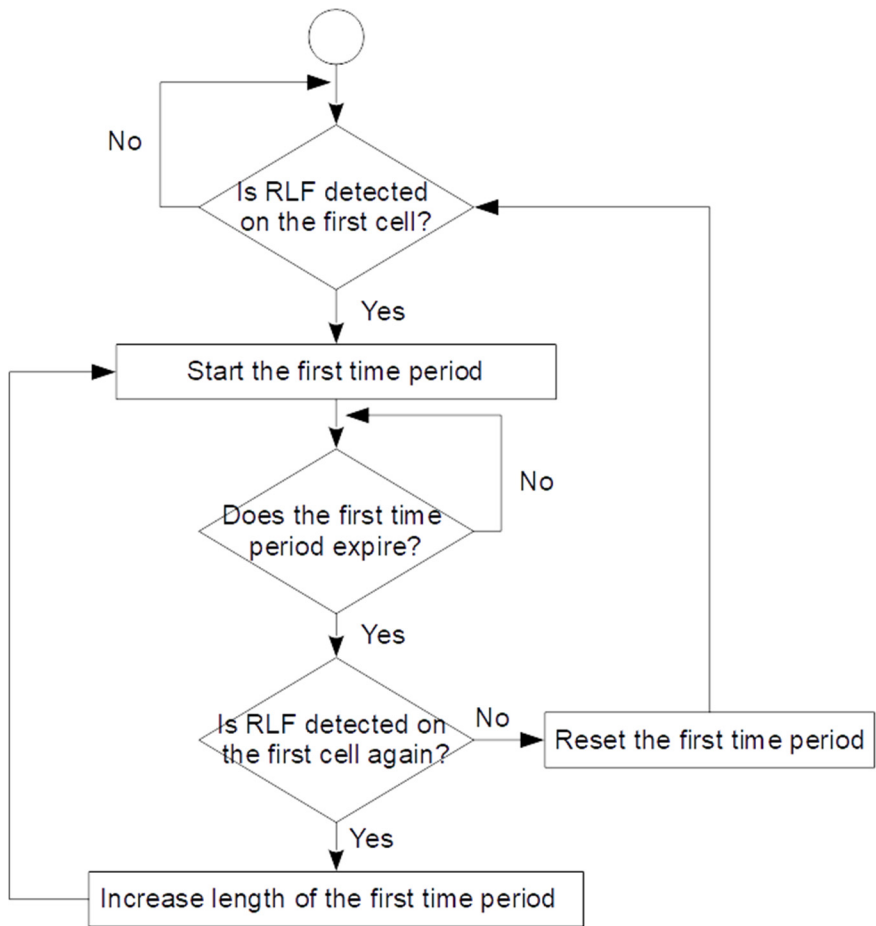
User equipment in a wireless communication system includes modems that convert digital data into a form suitable for transmission over the air, *e.g.*, to a base station, as well as receiving radiofrequency signals and converting them into digital data. In some cases, the signals representative of the digital data are modulated onto a carrier frequency to allow multiple wireless communication links to work concurrently on different frequencies. However, wireless signals are prone to interruption due to effects such as fading caused by changes in the environment, movement of the user equipment, and the like. An important modem performance metric is therefore the service interruption time during communication sessions. As used herein, the phrase “service interruption time” refers to a time interval during which a radio network is unable to provide data service for user equipment due to a radio link failure (RLF), a handover (HO) of the user equipment from one base station to another, or beam failure (BF). If the interruption time is too long, an ongoing phone call may be dropped or a transmission control protocol (TCP) protocol used to convey the wireless signals may enter a slow-start state that decreases data rate for communication between the user equipment and the network.

Description

Conditional handover techniques and fast master cell group (MCG) recovery have been standardized to speed up the handover process and the recovery from handover failures or radio link failure, which can shorten the service interruption time experienced by user equipment. These solutions focus on how to shorten the service interruption time after the occurrence of a radio link failure. However, an alternative to simply reducing the service interruption time is to prevent service interruptions from occurring in the first place. In some cases, the number or the frequency of the service interruptions is reduced by constraining when the user equipment is permitted to attempt to access the network. User equipment are not permitted to select (or reselect) a cell for camping or to (re)establish a radio resource control (RRC) connection to the network during a “prohibit time interval” following a radio link failure, which prevents the user equipment from camping or connecting to the network via the cell during the prohibit time interval.

The prohibit time interval is dynamically adjusted depending on whether radio link failures continue to occur on the same cell. For example, if a radio link failure happens on a cell, a prohibit time interval is started for the user equipment that attempted to access the cell. The prohibit time interval for the user equipment is then dynamically adjusted depending on whether a radio link failure subsequently happens again on the same cell. The prohibit time interval is increased in response to a subsequent radio link failure on the cell and decreased if no radio link failures are detected on the cell. Dynamic adjustment of the prohibit time interval reduces the likelihood of a radio link failure while also allowing the user equipment to use the cell after the carrier resolves any problems that are leading to the radio link failures.

The following figure is a flow diagram of a method of dynamically adjusting the prohibit time interval or user equipment. The method is initiated in response to a radio link failure (RLF) for user equipment attempting to access a cell in a network. Initiating the method includes initiating or triggering a first prohibit time interval and configuring the user equipment so that the user equipment is unable to connect to (or camp on) the cell for access to the network during the first prohibit time interval. The user equipment subsequently attempts to connect to (or camp on) the cell in response to expiration of the first prohibit time interval. If the user equipment successfully connects to (or camps on) the cell, the first prohibit time interval is reset, *e.g.*, to a configured time interval or a default time interval. However, if another radio link failure occurs for the user equipment on the cell, the first prohibit time interval is increased to a second prohibit time interval and the user equipment is prevented from connecting to (or camping on) the cell for the second prohibit time interval. In some cases, the second prohibit time interval is twice as long as the first prohibit time interval.



User equipment can detect a radio link failure using different techniques. The user equipment detects a radio link failure on the first cell if the block error rate on a first cell is higher than a threshold or the downlink signal is lower than a threshold for a period of time. In some cases, the radio link failure is caused by a downlink being out-of-sync on the first cell for a predetermined time interval.

The user equipment uses a timer to count the first prohibit time interval. For example, at the beginning of the first prohibit time interval, the user equipment starts the timer. The timer expires at the end of the first prohibit time interval. In some cases, the duration of the first prohibit time interval is constrained to be less than a maximum value. If the length of the first prohibit time interval is larger than the maximum value, the length is set to the maximum value.

A counter triggers transmission of a message recording the radio link failures to a base station in the network, e.g., in response to the counter reaching a threshold or maximum value. The user equipment increases the value of the counter by one in response to a radio link failure on the first cell. The user equipment resets the counter if no radio link failure occurs on the first cell. If the value of the counter reaches the maximum value, the user equipment sends a message to the base station to report problems at the first cell associated with the radio link failures.

Operation of the user equipment is constrained during prohibit time intervals to reduce the likelihood of a radio link failure. During the first prohibit time interval, the user equipment is not allowed to select or reselect the first cell to camp or to reestablish an RRC connection to the network. Constraining operation of the user equipment in this manner prevents the user equipment from camping or connecting to the network via the cell. However, if the first cell is the only cell available to the user equipment for camping or (re)establishing an RRC connection to the cellular network, and no other cell is eligible to be selected or reselected by the user equipment to camp or to establish/reestablish RRC connection to the cellular network, the user equipment can remove the restrictions imposed on the first cell. In other words, the user equipment can select or reselect the first cell to camp or to establish/reestablish a RRC connection to the cellular network.

If the user equipment detects another cell that is deployed on the same frequency as the first cell and the reference signal received power (RSRP) of the other cell is a predetermined number of decibels smaller than the RSRP for the first cell, the user equipment should not select or reselect the other cell to camp or establish RRC connection. Constraining the user equipment in this manner reduces or prevents interference to the first cell.

During the first prohibit time interval, the user equipment is not allowed to report measurements such as an RSRP, reference signal received quality (RSRQ), received signal strength indicator (RSSI), *etc.*, of the first cell in an RRC measurement report to the base station. This constraint prevents the base station from sending a handover command to command the user equipment to handover to the first cell. Alternatively, the user equipment may report a measurement with bad signal strength/quality for the first cell, expecting that the base station will not command the user equipment to handover to the first cell because of the poor signal strength or quality.

During the first prohibit time interval, if a measurement report is triggered but the first cell is the only cell available to receive the measurement report from the user equipment, the user equipment lifts the restrictions imposed on the first cell so that the user equipment can include the measurement of the first cell in the RRC measurement report.

The constraints on the operation of the user equipment are lifted in response to expiration of the first prohibit time interval. After the end of the first prohibit time interval, the user equipment can select or reselect the first cell to camp or establish/reestablish RRC connection to the cellular network. The user equipment can also include measurement of the first cell in the RRC measurement report and transmit the measurement report to the base station.

The user equipment then attempts to recover from the radio link failure problem after the expiration of the first prohibit time interval. However, the radio link failure problem may not have been resolved or another radio link failure problem may have occurred, in which case the user equipment detects a radio link failure as it attempts to recover from the previous problem. When a radio link failure problem is detected on the first cell during the recovery, the user

equipment determines that the radio link failure recovery has failed if the user equipment does not successfully reestablish RRC connection on during a second time period. In some cases, the user equipment turns on a Wi-Fi radio and tries to connect to the Internet via a Wi-Fi connection, e.g., to a Wi-Fi hotspot. Afterwards, if the user equipment successfully establishes or reestablishes an RRC connection to the cellular network on another cell, the user equipment turns off the Wi-Fi radio.

If a radio link failure problem is detected on the first cell after the user equipment establishes RRC connection to the cellular network, the user equipment transmits a report to a control entity which is located in the network. The control entity can be a base station or a computing entity in the cloud. The report includes the following unique identifiers:

- The unique identity of a first country where the first cell is located.
- The unique identity of a first cellular network in the first country where the first cell belongs to.
- The unique identity of a first tracking area in the cellular network where the first cell is located.
- The unique identity of the first cell.
- The longitude, latitude, and/or altitude where the radio link failure is detected.

Alternatively, to protect personal privacy, the report of the radio link failure problem includes the difference between the value of an identity to a reference value. Each type of identity (e.g., the cell id, network id, tracking id, etc) can have its own reference value. The central control can obtain an identity from the reported difference and the reference value. For example, the user equipment wants to report a cell identity which is 15. The reference value is 5.

Therefore, the user equipment reports 10 to the central control, which obscures the cell identity to anyone that does not have access to the reference value. The reference value is known by the user equipment and the central control. The central control or user equipment can determine the reference value and then sends it to another entity, i.e., the user equipment or central station, respectively. Alternatively, the reference value can be derived from a subscriber identity module (SIM) card according to a rule known by the user equipment and the central control. For example, the reference value for cell identity is the value stored in the SIM card minus a pre-defined value.

The user equipment also sends a report in response to failure of the radio link failure recovery process, *e.g.*, failure to camp or establish an RRC connection during a second time interval. The report includes a reason why the user equipment cannot successfully reestablish RRC connection during the second time interval. For example, the radio link failure recovery procedure includes two steps. The first step is to find a suitable cell and the second step is to finish the RRC reestablishment procedure. Thus, one possible reason is that the user equipment is unable to find a suitable cell. Another possible reason is that the user equipment is unable to finish the RRC reestablishment procedure. If the user equipment either cannot find a suitable cell or cannot complete RRC reestablishment procedure during the second time interval, the user equipment concludes that the radio link failure recovery fails.

In response to receiving the report from the user equipment, the control entity transmits a dedicated or a broadcast message to a second user equipment, telling the second user equipment to set up a third time interval for the first cell. In this way, the second user equipment can prevent a radio link failure problem on the first cell. The length of the third time interval is included in the message.

The user equipment also sends a report in response to a successful radio link failure recovery. For the case that the user equipment successfully reestablishes RRC connection on a cell, the report includes the information of how long it took the user equipment to find a suitable cell and the cell identity. After the control entity receives the report from the user equipment, the control entity transmits a dedicated or broadcast message that includes the cell identity to a second user equipment, telling the second user equipment to set up a third time interval for the first cell if the time to finish the RRC reestablishment procedure is longer than a threshold and to suggest to connect to the cell that is indicated in the message instead, which speeds up the search for a cell to establish RRC connection. For the case that user equipment successfully reestablishes RRC connection, the report includes the information of how long it took the user equipment to finish the RRC reestablishment procedure. After the control entity receives the report from the user equipment, the control entity transmits a dedicated or broadcast message to a second user equipment, telling the second user equipment to set up a third time interval for the first cell if the time to finish the RRC reestablishment procedure is longer than a threshold. The first cell may be crowded, i.e. a hot spot, at the time. The control entity can also send a message to the user equipment to configure the user equipment with the length of the first prohibit time interval.