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Signal Quality-Based Buffering of Media Data Using an Intermediate Device

Abstract:

This publication describes systems and techniques to buffer media data at an intermediate device based on a channel quality between a media source device and a media presentation device. In some environments with significant user movement, such as the gym or home, media packets may be dropped because a condition of a radio-frequency (RF) channel becomes worse over time. Consequently, media presentation may be interrupted. Users often have, however, multiple devices with different amounts of resources. For example, a user may have a smartphone, a smartwatch, and wireless headphones. The latter two are typically carried on a user's person, but the smartphone may be placed elsewhere. This disclosure describes using the smartwatch as an intermediate delivery device for media data because the headphones may not have the resources to buffer audio packets. To do so, the smartphone monitors a condition of a channel extending to the wireless headphones. If the condition worsens, as determined based on missing acknowledgements (ACKs) or a received signal strength indicator (RSSI), the smartphone pre-positions a media portion on the smartwatch. The smartwatch assumes delivery of the media data to the headphones. A predictive algorithm attempts to maintain a suitable buffer of media data on the smartwatch, which media data is transferred to the smartwatch each time the user is within range of the smartphone.

Keywords:

channel condition, radio-frequency (RF) channel, received signal strength indicator (RSSI), acknowledgement (ACK), intermediate device, secondary device, wearable, audio device, headphones, personal area network (PAN), Bluetooth^{TM}, media source device, buffer, cache

Background:

As device ecosystems grow, more users own three different devices, such as a smartphone, a smartwatch, and wireless headphones. Users wear smartwatches that can locally store media data and play the media on wireless headphones, such as by using an Advanced Audio Distribution Profile (A2DP) of a Bluetooth^{TM} connection or audio over Bluetooth^{TM} Low-Energy (LE). However, because it is easier to browse media options on a phone or tablet due to the larger screen, many users continue to use their smartphones to select and stream media items. These users therefore also rely on the smartphone as the host in the Bluetooth^{TM} connection.

In some environments, users may place their smartphone in a stationary position while continuing to move around the environment. An example of such an environment is the gym where a person walks from station to station or may detour to a water fountain. Another example is the home where a person may walk around a great room or between different rooms while performing chores. In these scenarios, a condition of an RF channel can worsen, and audio packets may be dropped as a result. This produces a poor listening experience for the user. If a user is listening to media, such as a song, podcast, or audiobook, on wireless headphones, the user will experience audible stutter, audio drops, and potentially even a total loss of audio if the quality channel is sufficiently poor.

An RF channel may degrade for several reasons. First, a user may enter an area where reflected waves are not easy to create, such as the outdoors. Second, a user may move so far from the smartphone that the distance is too great for a Bluetooth™ connection despite having a clean RF environment. Third, a user may move into another room where reflected waves cannot be readily received. For instance, with a wall separating the smartphone from the headphones, some medium (e.g., a sheet of metal in the wall) can cause interference and signal degradation.

If a user is wearing a smartwatch or other on-body wearable device (such as glasses), the user is unlikely to remove the wearable. Further, it is likely that the wearable device will be relatively closer to the wireless headphones than is the smartphone. Therefore, it is desirable to leverage the wearable device to maintain a constant stream of audio so that the user does not detect drops due to small or short-duration movements in and out of a good reception area.

Description:

This publication describes systems and techniques for using an intermediate device, such as a wearable, to buffer media data being streamed to a media presentation device if a channel between a media source device and the media presentation device has a poor quality. Fig. 1 below illustrates an example environment 100 for buffered media streaming with three devices.

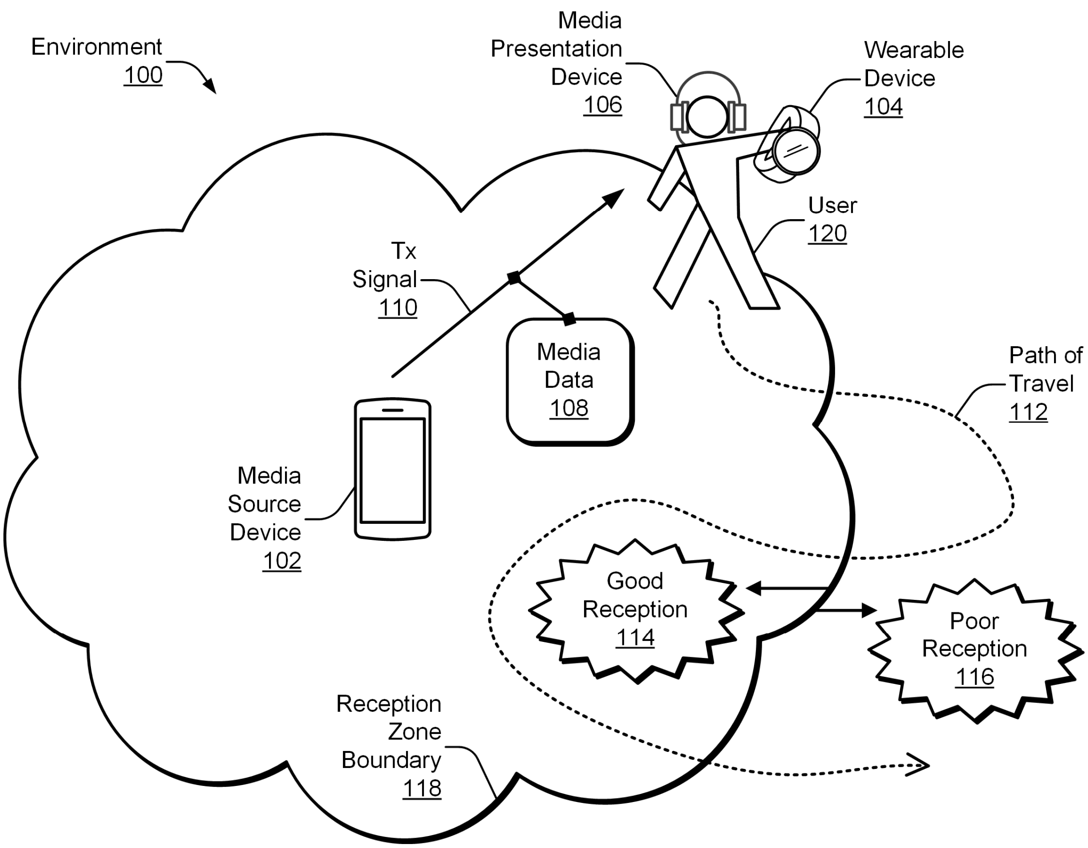

Fig. 1

As shown in Fig. 1, the environment 100 includes a media source device 102, a wearable device 104, and a media presentation device 106. The media source device 102 can be realized by a smartphone, a tablet computer, a media streamer, a smart speaker or video communication device, and so forth. The wearable device 104 can be realized as a smartwatch, intelligent glasses, smart clothing, electronic jewelry, and so forth. The media presentation device 106 can be realized as wireless headphones—such as over-the-ear headphones, on-ear headphones, earbuds, neck/shoulder speakers, etc.; glasses with a display screen or projector; and so forth. A user 120 is carrying the wearable device 104 and the media presentation device 106. The media source device 102, however, is left at some stationary position in the environment.

Initially, the media source device 102 streams media directly to the media presentation device 106. As shown, the media source device 102 provides media data 108 to the media presentation device 106 using a transmission (Tx) signal 110. The user 120 is in motion and follows some path of travel 112. As the user 120 follows the path of travel 112, a quality of the reception at the media presentation device 106 varies with respect to transmissions from the media source device 102. There are times and/or positions of good reception 114 and poor reception 116. Although scenarios described herein focus on a stationary media source device 102 and a moving media presentation device 106, other scenarios are also applicable. For example, the media presentation device 106 may be stationary while the media source device 102 is in motion. Further, both may be in relative motion such that the media presentation device 106 changes between being in areas of good reception 114 and being in areas of poor reception 116.

Over time, a reception zone boundary 118 can be approximately determined. The good reception 114 is on one side of the reception zone boundary 118, and the poor reception 116 is on the other side. Thus, the RF condition within the reception zone boundary 118 is generally good enough for the user 120 to move around without experiencing any detectable audio drops. Fig. 2 below illustrates an example media streaming approach if the user 120 is at least predominantly on the good reception 114 side of the reception zone boundary 118.

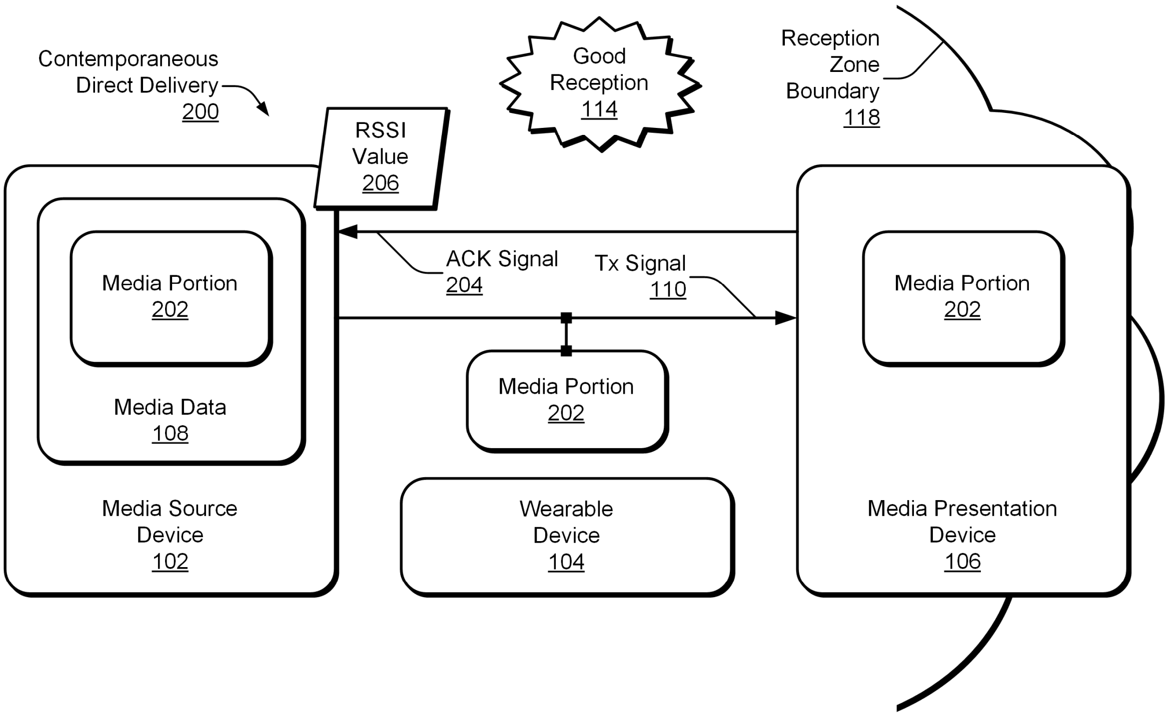

Fig. 2

Fig. 2 depicts an example of contemporaneous direct delivery 200 from the media source device 102 to the media presentation device 106 responsive to having good reception 114. Here, the media presentation device 106 is generally on the good reception 114 side of the reception zone boundary 118 as shown. The media source device 102 stores or otherwise has access to the media data 108, including at least one media portion 202. The media portion 202 can include some quantifiable part of the media data 108. Examples of the media portion 202 include a song, two minutes of sound, one megabyte (1 MB) of media data, and so forth.

In operation for the contemporaneous direct delivery 200, the wearable device 104 is "bypassed." For this unbuffered media delivery, the media source device 102 transmits the media portion 202 to the media presentation device 106 using the transmission signal 110. The media presentation device 106 receives the media portion 202 and stores the media portion 202 for processing and presentation to the user 120. In response, the media presentation device 106 transmits an acknowledgement (ACK) of receipt of the media portion 202 using an ACK signal 204. Upon receiving the ACK signal 204, the media source device 102 knows that the transmitted media portion 202 was successfully received.

Receipt or lack of receipt of the ACK signal 204 is one indication of channel quality between the media source device 102 and the media presentation device 106. Another indication of channel quality is a received signal strength indicator (RSSI) value 206. The media source device 102 can measure the RSSI value 206 based on a received ACK signal 204. These indications of channel quality, as well as others, can be monitored to estimate the channel quality and infer whether the user 120 may be subjected to sputtering, halting, or otherwise poor media presentation. Fig. 3 below illustrates a flow diagram 300 of an example process for switching from streaming media responsive to the media presentation device 106 having good reception 114 to streaming media responsive to the media presentation device 106 having poor reception 116.

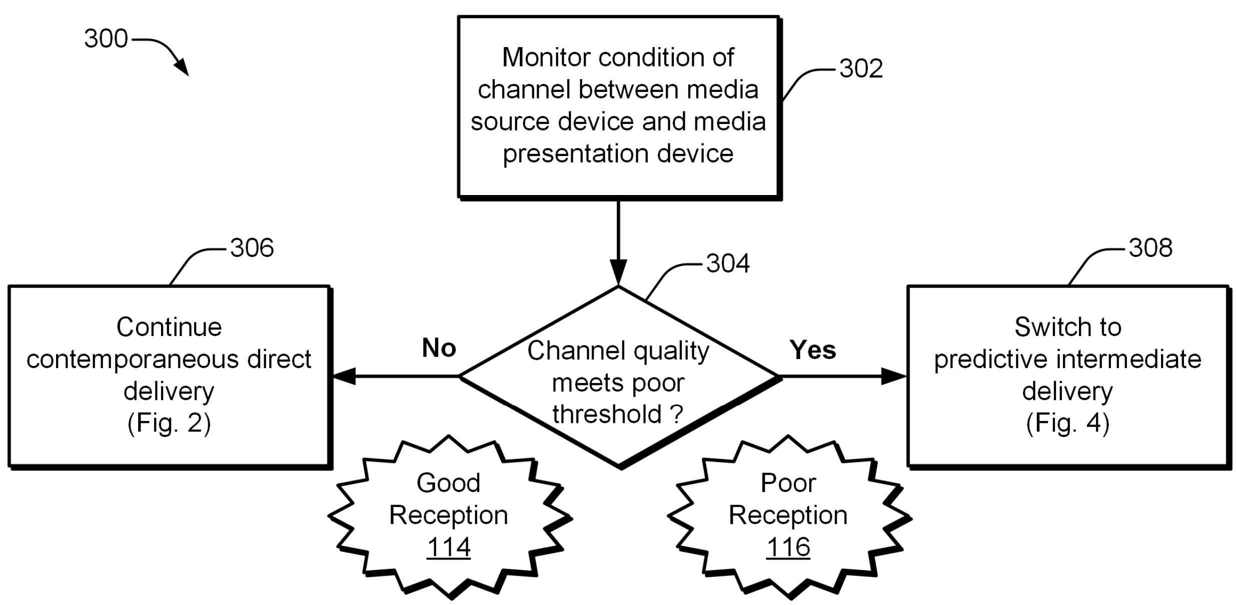

Fig. 3

As shown in Fig. 3 at 302, the media source device 102 monitors a condition of the channel between the media source device 102 and the media presentation device 106. For example, the media source device 102 can log ACK signals 204, track measured RSSI values 206, and so forth. At 304, the media source device 102 determines if the channel quality meets at least one poor-quality threshold. For example, an average of multiple RSSI values 206 can be compared to a threshold signal strength level. Additionally or alternatively, a quantity of missing ACK signals 204 over time can be compared to a threshold rate. If the channel quality does not meet the poor threshold, then at 306 the media source device 102 continues contemporaneous direct delivery 200 of the media data 108 to the media presentation device 106. This is described above with reference to Fig. 2. If, on the other hand, the channel quality does meet the poor threshold, then at 308 the media source device 102 switches to predictive intermediate delivery.

Predictive intermediate delivery 400 involves buffering at least one media portion 202 in the wearable device 104 for subsequent forwarding to the media presentation device 106. Predictive intermediate delivery 400 is described below with reference to Fig. 4. However, example approaches for determining if a channel quality meets at least one threshold are described next. These approaches are described in terms of audio media by way of example.

The existence of poor RF conditions can be detected in several ways. First, an indication that an RF channel is poor can include missing a number of audio packet acknowledgements, such as the ACK signals 204, despite retransmissions of the same sequence number. Second, another indication of a poor RF channel can be measuring an RSSI value 206 that is below an acceptable level. One or more of these approaches can be used individually, simultaneously, jointly, and so forth. Although two approaches are explicitly described (ACK and RSSI-based approaches), other approaches for detecting a poor RF condition can additionally or alternatively be implemented.

Two example RF-condition analysis schemes are described. In a first example scheme, an RSSI value is taken between the media source device 102 and either the wearable device 104 or the media presentation device 106. The RSSI value can be coupled to missed ACKs to estimate a radius or distance to the reception zone boundary 118. The RSSI value is logged, and some error bars (+/– some range) are applied to compute a radius estimate. The RSSI value is adjusted the next *N* times that a "low" RSSI value (which low value can be set) is detected and missed ACKs are not received. Responsive to reaching some threshold number of detections of the user 120 exiting and/or entering a circle determined by the estimated radius, local buffering to the wearable device 104 can be activated.

In a second example scheme, a manual threshold is set at which the media buffering is activated. This threshold may be based, for instance, on a count or rate of missed ACKs or low RSSI values or on exceeding at least one criterion of the following criteria. A first criterion involves a quantity of missed ACKs in a time period *t* (e.g., a 30-second time period). A second criterion involves a moving average of RSSI values using a time window that may be variable.

If the user 120 is not within the reception zone boundary 118 for very long at each reentry, the media source device 102 may elect to use Wi-Fi Direct for streaming media data to the wearable device 104 because the range is longer and the bandwidth is higher. Thus, a transfer can occur more quickly and at more potential positions of the user 120. The media source device 102 and the wearable device 104 may also persist a Wi-Fi connection between them, so the wearable device 104 can render and stream the media data to the media presentation device 106.

Fig. 4 below illustrates an example media streaming approach if the user 120 is predominantly on the poor reception 116 side of the reception zone boundary 118.

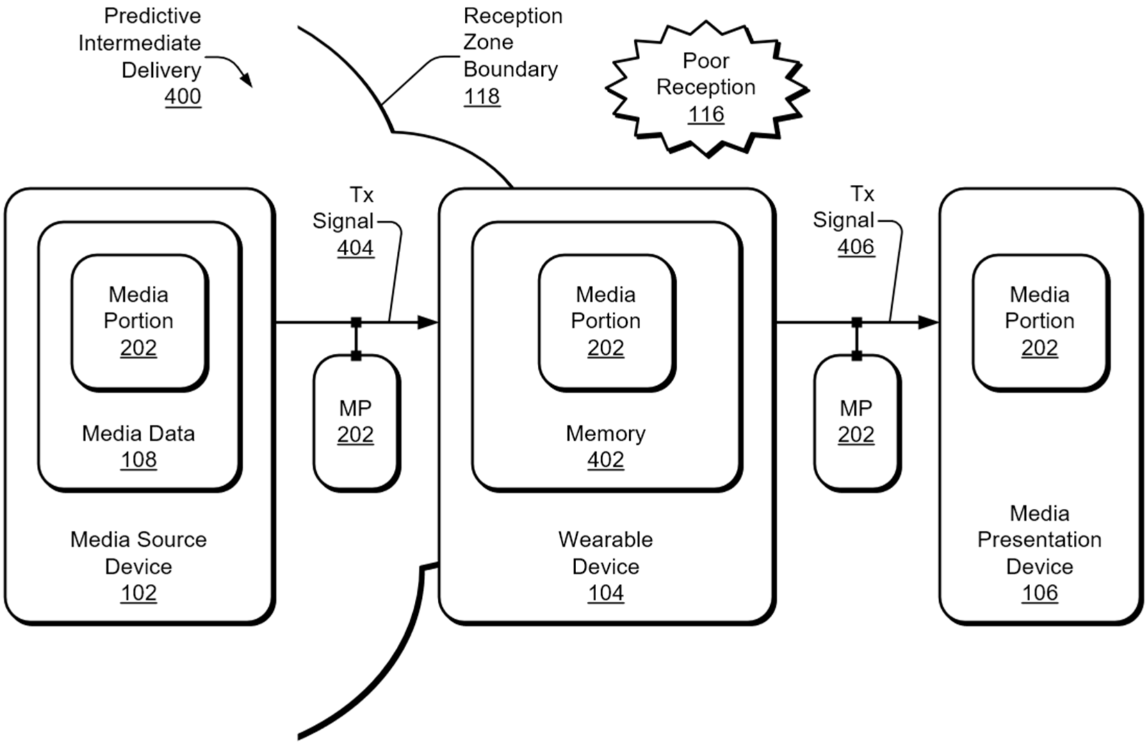

Fig. 4

Fig. 4 depicts an example of predictive intermediate delivery 400 from the media source device 102 to the media presentation device 106 by way of buffering with the wearable device 104 responsive to poor reception 116. As shown, the media presentation device 106 is generally on the poor reception 116 side of the reception zone boundary 118. In operation, the wearable device 104 is used as a "proxy" to forward-deploy or cache the media portion 202 physically nearer the media presentation device 106 because both the wearable device 104 and the media presentation device 106 are expected to be carried by the user 120. For this "buffered" media delivery, the media source device 102 transmits the media portion 202 to the wearable device 104 using a transmission signal 404. The wearable device 104 stores the media portion 202 in a memory 402. Subsequently, the wearable device 104 transmits the media portion 202 to the media presentation device 106 using a transmission signal 406 to thereby stream the media data 108 to the media presentation device 106. The media presentation device 106 receives the media portion 202 and stores the media portion 202 for processing and presentation to the user 120.

Example approaches to buffering at an intermediate device, media data 108 that is being streamed to a media presentation device 106, are now described. Some of these approaches can be facilitated by tight integration between the media source device 102 and the wearable device 104. For example, each device may be manufactured by the same company or have an operating system built by the same company. Additionally or alternatively, a single company may produce media streaming or delivery apps for both devices that are designed to interoperate with one another.

Although the buffering approaches are described below in terms of streaming audio using a Bluetooth™ protocol, the described approaches are applicable to other environments such as streaming video or another media type and/or using a different wireless protocol. For example, a different wireless personal area network (WPAN) standard can be used to deliver media data to the media presentation device 106, or a direct Wi-Fi protocol can be used for communications between the media source device 102 and the wearable device 104. Also, by way of example, a smartphone is used as an example of a media source device 102, and wireless earbuds are used as an example of a media presentation device 106.

Initially, it is determined if the dynamic RF conditions are suitable for engaging a media buffering feature, as is described above in terms of ACK signals or RSSI values. If the RF channel conditions are suitably poor, then a streaming operation switches from a first state to a second state. In the first state, the smartphone operates as the host and streams audio directly to the wireless earbuds. The wearable is connected to the smartphone over Bluetooth™ LE (BLE) or at least knows the smartphone and the earbuds exist via LE scans. In the first state, the wearable is not involved with the audio streaming to the earbuds. In the second state, the wearable becomes involved in the audio streaming by serving as an intermediate buffering device.

To switch from the first state to the second state, and to operate the devices in the second state, the following actions are performed. First, the smartphone sends the wearable information about the connection that the smartphone currently has with the wireless earbuds. Second, the smartphone, as the host, begins streaming pulse-code modulation (PCM) audio, which is audio that is not yet encoded by an audio framework or digital signal processor (DSP), over BLE to a memory that is acting as a buffer storage on the wearable. Alternatively, the smartphone can encode the media data and transmit the encoded packets to the wearable so that the wearable can save power. The wearable can then relay the encoded packets to the wireless earbuds. The smartphone can also send timestamp information and metadata on the current place in the song, an identifier of the next song, or other audio timing or planning information. Third, the smartphone checks with the wearable to ascertain how much memory (e.g., flash storage) is available for buffering streaming media data. Fourth, the wearable returns a value indicating an offer to allocate a block of memory of size *X* bytes, along with a pointer to the start of this memory block. The last address of the block can be calculated by, for instance, an offset pointer_address + offset.

Fifth, the wearable "silently" connects to the wireless earbuds, and the smartphone disconnects from the earbuds. Alternatively, the wearable may not formally "connect" and may instead use a connectionless audio streaming method, such as BLE broadcast, which is described in the BLE audio specification. Sixth, the wearable begins streaming audio data to the earbuds by pulling the audio data from the buffer storage that the smartphone requested the wearable allocate.

Seventh, when the wearable returns to being in range—after being out-of-range—the smartphone transfers additional media portions (e.g., a next track or tracks to be buffered) into the newly-available memory space on the wearable. This media data transfer may occur over BLE, such as by using the 1M physical layer (PHY) protocol for range or the 2M PHY protocol for speed at the expense of range. Alternatively, the transfer may occur over Wi-Fi Direct, which enhances speed and range at the expense of power. Further, the transfer may be performed over any other wireless technology, including using wideband or ultrawideband protocols.

Eighth, the smartphone sends the rest of a currently-playing song to the wearable to store in memory. If a current location in this song is in the last *y*% of the track, the smartphone begins to preemptively buffer a next predicted track or other audio portion. The next predicted track may be the next track in a playlist or may be a track identified in response to a query of a shuffling engine that determines a next shuffled track. The "next track" may also or instead be predicted by some behavior-trained machine learning (ML) model that predicts how and when a user changes songs. Ninth, responsive to each time the wearable returns to being in range, the eighth action is repeated. If the amount of memory space allocated on the wearable is not enough, such as if the user 120 exits the good reception 114 area for longer periods of time and the buffer is emptied, then the wearable can communicate this to the smartphone and allocate a larger space. Thereafter, the smartphone can preemptively buffer more media data (e.g., more songs or longer audio).

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