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QUALITY-PERCEIVED MULTIPLE LABEL-SWITCHED PATHS FOR ACHIEVING ULTRA-RELIABLE WI-FI FOR INDUSTRIAL IOT DEPLOYMENTS

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ABSTRACT

Operating within an environment that incorporates technologies based on Multiprotocol Label Switching (MPLS) and the Label Distribution Protocol (LDP) to provide an ultra-reliable wireless backhaul service supporting large Internet of Things (IoT) and Industrial IoT (IIoT) environments (comprising, for example, many hundreds of radio devices), techniques are presented herein that support a mechanism to implement quality-perceived multiple label-switched paths (LSP)s that can perform replication according to path quality. Aspects of the presented techniques leverage a replication strategy, that is defined on both a client and a Network Appliance that defines how replication should be performed with preconditions, replication should be stopped when the preconditions are not met, or replication should be recovered when a precondition is met. According to aspects of the presented techniques, when a strategic precondition is met or not met, the corresponding LSP state is changed to "pending" or "recovered" (respectively) instead of being torn down or being rebuilt.

DETAILED DESCRIPTION

The techniques that are presented herein, which will be described and illustrated in the narrative that is presented below, operate in an environment that provides wireless Internet Protocol (IP) backbone systems for mission critical applications comprising high-bandwidth, low-latency facilities for on the move assets and mission-critical applications enabling outdoor and large-scale applications for Internet of Things (IoT) environments – e.g., smart cities, urban video-surveillance, connected vehicles and trains, industrial automation, etc. For convenience, the context that was just described may be referred herein to as ‘the operating environment.’

The operating environment incorporates unique technology based on Multiprotocol Label Switching (MPLS) and the Label Distribution Protocol (LDP) to provide an ultra-reliable wireless backhaul service to customers. Various of the incorporated functionalities include, for example, mobility management in label switched networks, mobility management in communication networks, and the automatic selection of detour paths in a wireless mesh network.

Figure 1, below, depicts elements of a typical topology for the operating environment.

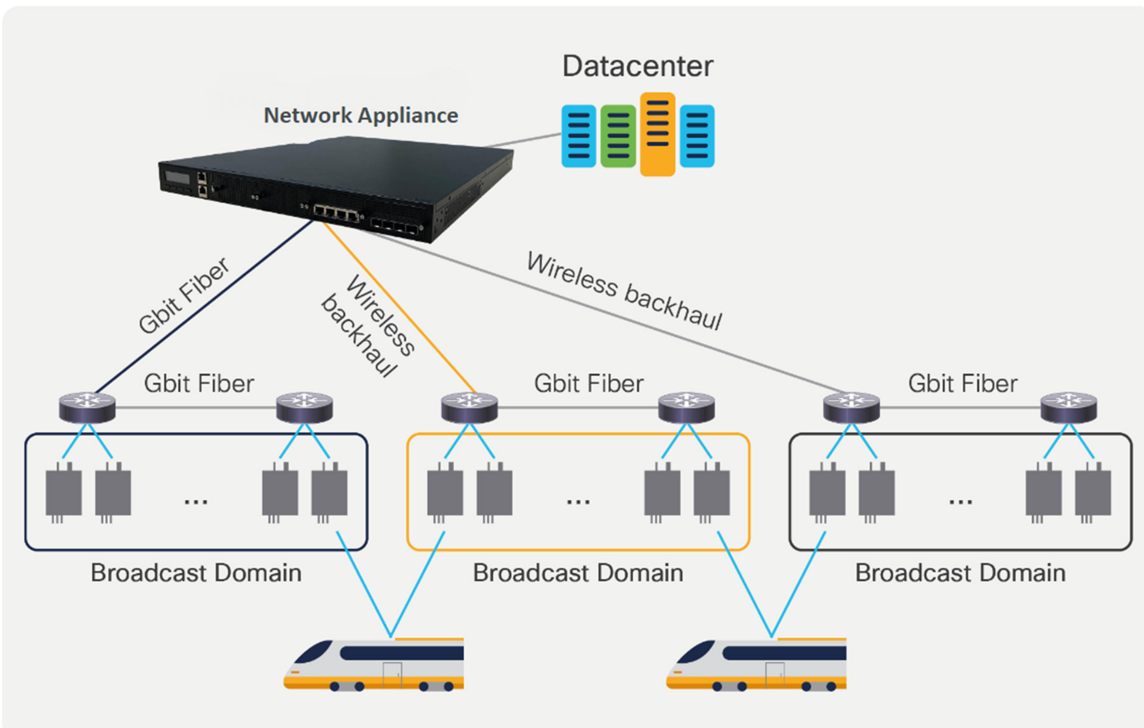

Figure 1: Exemplary Topology

Note that in Figure 1, above, the element that is labeled ‘Network Appliance’ represents an industrial-grade network appliance that offers rapid and easy construction of MPLS-based wireless systems for the delivery of Internet Protocol (IP)-encapsulated data in support of, for example, large IoT and Industrial IoT (IIoT) environments (comprising, for example, many hundreds of radio devices).

One particular approach for providing a modular and reliable Wi-Fi client device makes use of multiple (i.e., N) client radios to take advantage of spatial diversity and packet replication to provide reliable low-latency communication in harsh IIoT environments. The approach's operation allows for hardware modularity, such that N is a user-controlled parameter that supports a reliability versus redundancy (e.g., cost) tradeoff that may be adjusted.

Techniques herein provide support for both wireless and wired links, including providing LDP for wired technologies, as well as facilitating link quality coordination between wireless and wired links.

For purposes of illustration, as depicted in Figure 2, below, consider that LSP1 and LSP2 are created at the same time and traffic is replicated on both LSP1 and LSP2. In this way, ultra-reliability may be achieved.

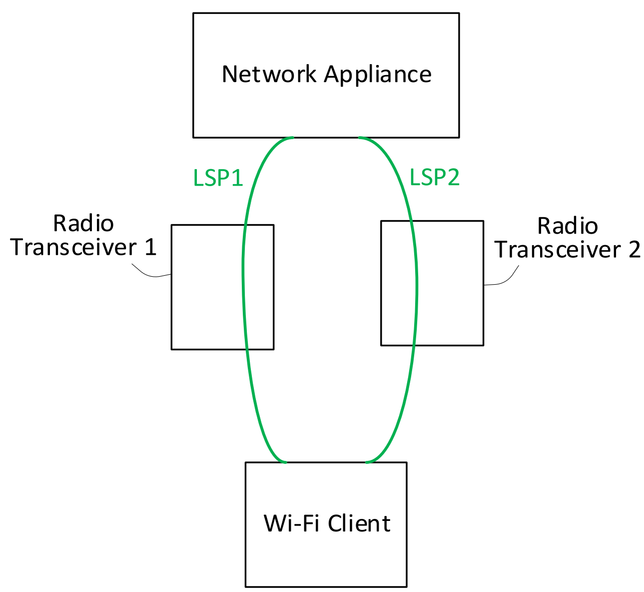

Figure 2: Illustrative Ultra-Reliability with Multiple LSPs

Note that in Figure 2, above, the elements that are labeled 'Radio Transceiver' represent ultra-reliable, high-performance radio transceivers that support, among other things, the reliable backhaul of mission-critical video, voice and data in, for example, point-to-point, point-to-multipoint, mesh, and mobility wireless networks.

Providing ultra-reliability through replication can introduce extra traffic within a Wi-Fi environment and, thus, cause additional bandwidth to be consumed. Such a deficiency can raise several issues. First, in a dense deployment, too much replication can result in more collisions over the air. Second, when one LSP is operating well, the replication on alternative LSPs is unnecessary but such replication cannot be stopped. Third, when the quality of one LSP is not good, the system may tear down the LSP and then rebuild it after the quality returns to normal. Such activity results in extra LDP message exchanges. For example, as illustrated in Figure 3, below, the Wi-Fi signal is becoming poor between the client and Radio Transceiver 2 and thus LSP2 must be eliminated and then rebuilt when the Wi-Fi signal returns back to normal.

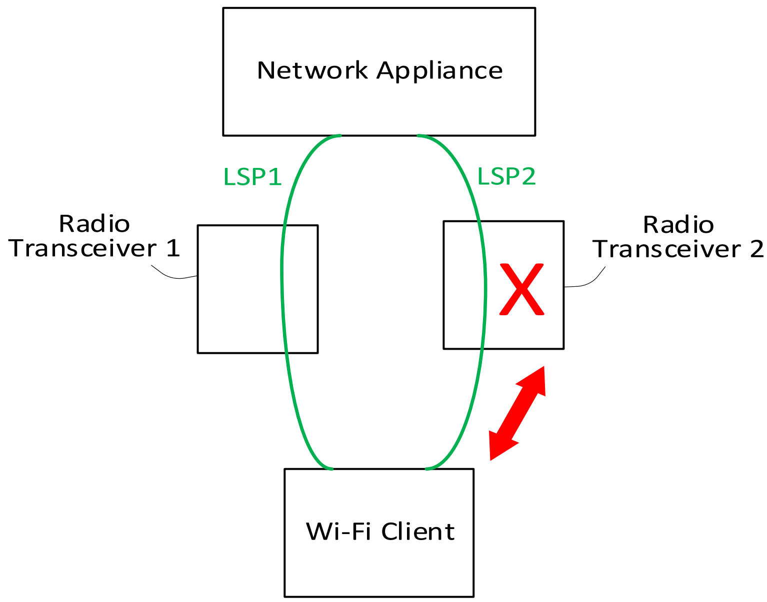

Figure 3: Exemplary Poor Wi-Fi

The Network Appliance that as depicted in Figures 1 through 3, above, is not aware of the Wi-Fi quality between a client and different access points and, as a result, performs replication on multiple LSPs unconditionally for downstream traffic. Consequently, there is a need to implement quality-perceived multiple LSPs, which can perform replication according to path quality so as to seek a balance between replication and ultra-reliability.

To address such a need, techniques are presented herein that support a mechanism to implement quality-perceived multiple LSPs which can perform replication according to path quality.

Aspects of the techniques presented herein may be explicated with the aid of the illustrative example that will be described and illustrated in the following narrative.

Under a first step of the illustrative example, when a client desires to have ultra-reliable Wi-Fi if the client has redundant radios, then it just follows the approach as described above and builds multiple LSPs. Figure 4, below, depicts elements of such a situation.

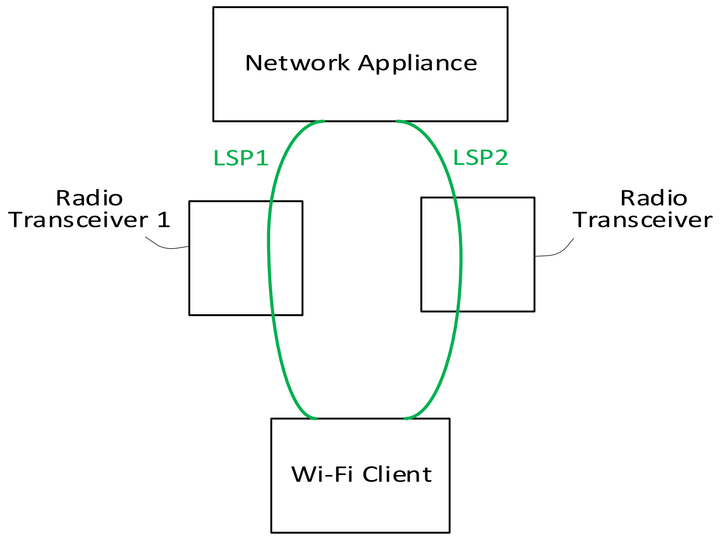

Figure 4: Exemplary Multiple LSPs

Under a second step of the illustrative example, a replication strategy is defined on both the client and the Network Appliance. The basic rule of this strategy is that replication is to be performed with preconditions such that replication should be stopped when the preconditions are not met or replication should be recovered when a precondition is met. There are several options to define such a strategy, two of which will be briefly described below.

A first option incorporates Wi-Fi link quality. For example, a quality threshold may be defined against a received signal strength indicator (RSSI). Replication may be stopped when the RSSI is lower than the threshold or replication may be recovered when the RSSI is higher than the threshold.

A second option incorporates a Wi-Fi link quality delta. For example, when a quality gap of multiple Wi-Fi links is larger than a delta, replication may be triggered. Alternatively, when the gap is small, and all of the Wi-Fi links are good, then replication may be be stopped.

Under a third step of the illustrative example, whenever the strategy precondition is met or not met, the corresponding LSP state is changed to "pending" or "recovered" (respectively) instead of being torn down or being rebuilt. Figure 5, below, illustrates elements of this approach.

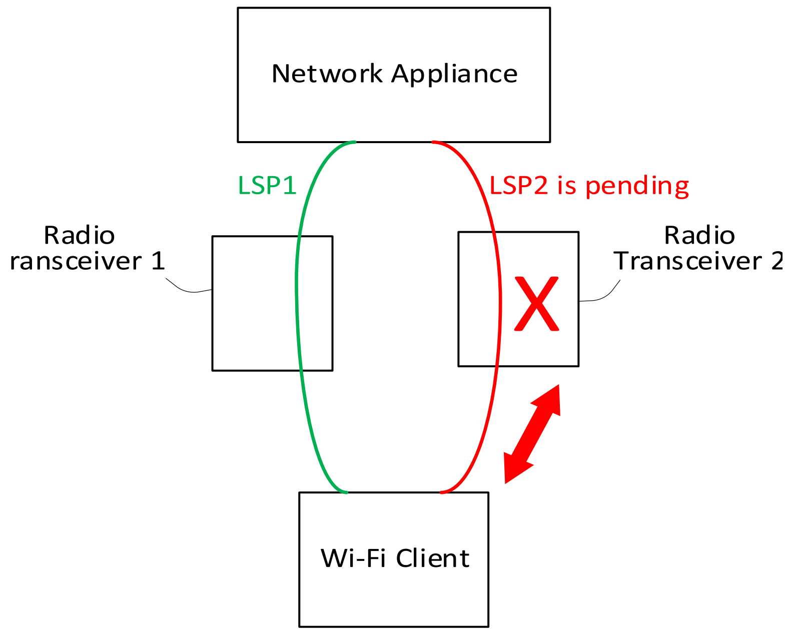

Figure 5: Illustrative LSP State Change

Under a fourth step of the illustrative example, there are several options that are available for pending or recovering an LSP. One such option includes providing a customized "Label Mapping Message" through which bits of a Forwarding Equivalency Class (FEC) type-length-value (TLV) or a Label TLV may be borrowed to inform a peer that a certain label needs to set as "pending." To recover the LSP, a normal "Label Mapping Message" may be sent to the LSP. It is important to note that other mechanisms to set a LSP to pending are available.

As described above, the first two bits of both a FEC TLV and a Label TLV may potentially be used. A FEC TLV has the following structure:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0| FEC (0x0100)              |      Length                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        FEC Element 1                          |
```

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~                                                               ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        FEC Element n                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

A Label TLV has the following structure:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0| Generic Label (0x0200)    |      Length                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Label                                                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

As shown in Figure 6, below, consider an example in which the client decides that replication should be stopped on LSP2. According to strategy, the client sends out a "Label Mapping Message with Bit Mark" to Radio Transceiver 2. Radio Transceiver 2 then forwards the message to the Network Appliance. The Network Appliance then sets the state of LSP2 to "pending" and stops replication on LSP2 for downstream traffic.

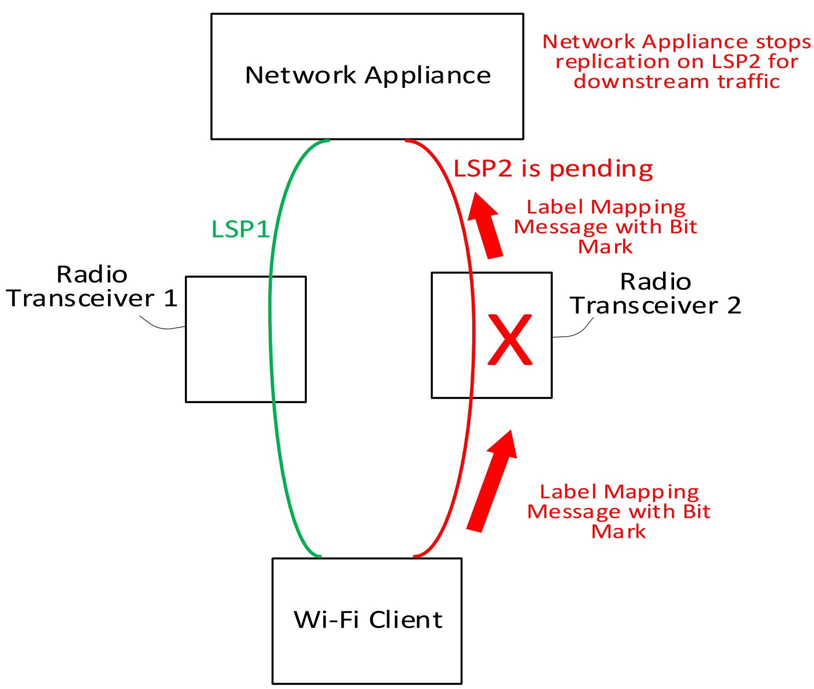

Figure 6: Illustrative Replication Management

It is important to note that alternatives exist to the approach that was described and illustrated above. For example, it is possible to perform replication on a per-packet basis (e.g., replicating packets based on a Quality of Service (QoS) measure such as type of service (ToS), Class of Service (CoS), etc.) instead of marking an entire path as pending or recovered. However, such an approach does not resolve the targeted problem that is addressed by the techniques presented herein. When a wireless link is inadequate, any packet transmission over the link can result in numerous re-transmissions or collisions over the air. Thus, stopping the transmissions in such a case is better for maintaining the overall performance of the wireless network. This is particularly true in an environment comprising a mixture of wireless and wired networks, where coordinating the link quality between wireless elements and wired elements is greatly desired. Aspects of the techniques presented herein support, among other things, such functionality.

In summary, techniques have been presented that support a mechanism that implements quality-perceived multiple LSPs which can perform replication according to path quality. Aspects of the presented techniques leverage a replication strategy, that is defined on both a client and a Network Appliance, that defines how replication should be done with preconditions, replication should be stopped when the preconditions are not met, or replication should be recovered when a precondition is met. According to aspects of the techniques presented herein, when a strategy precondition is met or not met, the corresponding LSP state is changed to "pending" or "recovered" (respectively) instead of being torn down or being rebuilt.