QoS in Information-Centric Networks

Disaggregated Name Component Approach

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Outline

- Motivation
- Name based QoS encoding
- Network procedures
- Discussion
- Summary & future work

Motivation

- A new approach towards implementing name-based QoS in ICN
- Our earlier DSCP based QoS design was based on IP primitives
  - https://datatracker.ietf.org/doc/draft-anilj-icnrg-icn-qos/
- A new proposal is inspired by our interpretation and feedback we provided to the ICN flow-classification draft
  - https://www.ietf.org/mail-archive/web/icnrg/current/msg02619.html

Our Interpretation of Flow-class and QoS

Some important differences between flow-classification and name-based QoS marking

Flow-classifier		QoS Marker
Identify the type of data flow	⟷	Identify the treatment for data flow
Set by the producer	⟷	Set by the consumer
Immutable for the lifetime of Interest	⟷	May be modified in the network
Part of routable name	⟷	Not used in prefix matching

Name-based QoS Encoding

- Improvement over DSCP based QoS
- Disaggregated name components

QoS Marker in the Content Name

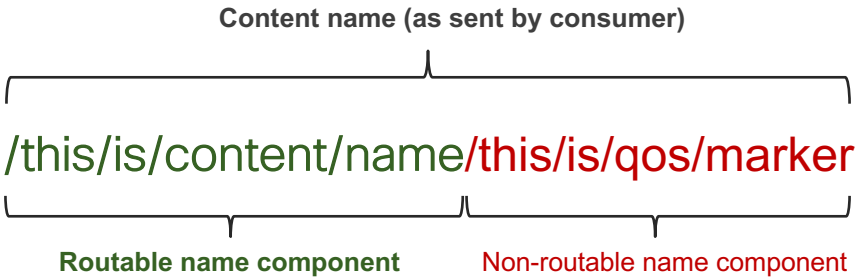
- Contrary to encoding of DSCP codes in the Interest body, QoS markers information is encoded in the content name
- More **space** compared to limited (1 byte) of DSCP field
  - Finite number of QoS markers, but large enough compared to the number of DSCP codes
- A **naming scheme** to be used to define name based QoS markers
  - Can follow either flat or hierarchical naming scheme
- QoS marker can be encoded in content name similar to path parameters in HTTP URI

What are Path Parameters?

- Path parameters are variable parts of a URL path, which are used to point to a specific resource within a collection e.g. a user identified by ID
  - https://swagger.io/docs/specification/describing-parameters/#path-parameters
- URIs often use reserved characters allowed in a segment to delimit scheme-specific or dereference-handler-specific subcomponents
  - The semicolon (";") and equals ("=") reserved characters are often used to delimit parameters and parameter values applicable to that segment
    - https://tools.ietf.org/html/rfc3986#section-3.3 (last paragraph)
- CCNX also provides a mechanism (application payload name segments)
  - More investigation required to check if this can be used
  - Refer section 3.6.1.1@draft-irtf-icnrg-ccnxmessages-08.txt

Disaggregated Name Components

- A logical separation and independence between the content name and the QoS marker
  - Content name is the **routable** component of the name
  - QoS marker is **non-routable** component of the name
- Separation between content name and the QoS marker can be modeled similar to **path parameters** used in HTTP URI



Note: This is just a logical representation, actual encoding details are being worked upon

Network Procedures

- Consumer behavior
- Forwarder behavior
- Producer behavior

Consumer Procedure

- Consumer sends out the Interest into the network and adds the QoS marker per his service subscription and/or quality needs
  - If consumer does QoS marking, it may be able to add it as name parameter (i.e. as path parameter) in the content name
  - If network does QoS marking, it has to put it in a separate field of the message
    - It shall be based network's (e.g. MME or AMF) authentication of user's subscription

- Questions:
  - Should we allow the network (forwarder) to modify the QoS marker, i.e. non-routable component of the content name?
  - Should we design the QoS marking such that the relationship between the consumer's SLA and its QoS marking is explicit?

Forwarder Procedure

- Forwarder preserves the **QoS marker against the Interface** it receives the Interest on
  - Enhancement to PIT to map the QoS marker against the Interface (in addition to name)
- Forwarder **forwards** the Interest only **using the routable name** component
  - Unlike PIT, there is no change in the FIB table; however, both (content name and QoS marker) are forwarded to upstream router
- Forwarder may **use QoS marker** in the **forwarding decision** for example:
  - Selecting a low delay (high b/w) over a high delay (low b/w) interface (QoS aware forwarding)

- Questions:
  - After upstream interface is selected, how to map QoS marking with the queue?
  - Should we allow **remarking** of QoS and is one marker enough for it?
    - Preserve original marker added by subscriber and have a running marker set by the network
  - How does user of the system know what network is doing with their QoS marking?

Producer Procedure

- Producer is aware of disaggregation between QoS marker and routable name and looks up the content using routable name component
- The way producer hands over the Data packet to the network may depend on the QoS marker it receives in an Interest
- Producer may respond with a Data packet depending on the QoS marker
  - This could be an in-network content adaptation scenario
  - Question: should/can the content with same name be preserved with two different formats (i.e. original and transcoded)?
- If content is found in an intermediate router node's content cache, it follows the same producer behavior as described above

Discussion

- Enhancement to PIT
- Multiple Interest handling
- Multiple Interest optimization
- Mutable QoS Markers
- Advantages

PIT Enhancement

- PIT to maintain the mapping of Interface + Content Name + QoS Marker

Pending Interest Table (PIT)		
Interface	Content name	QoS marker
/face-1	/this/is/content/name	/this/is/qos/marker-1

Multiple Interest Handling
(PIT Scaling Issue)

Pending Interest Table (PIT)		
Interface	Content name	QoS marker
/face-1	/this/is/content/name	/this/is/qos/marker-1
/face-1	/this/is/content/name	/this/is/qos/marker-2

- Assume that multiple Interests (for same content) are received on the same Interface, but with different QoS markings
  - Since QoS markers are different, forwarder forwards both the Interests upstream, creating two PIT entries as shown in the table
- In order to support this, the PIT aggregation to be loosened up proportional to the number of unique QoS markers (for given content)
  - If not, upstream forwarder looses an opportunity to obey each of the QoS treatment
  - The upper bound on the PIT scaling will be equal to number of QoS markers
- The impact on PIT scaling can be minimized by
  - Keeping the # of QoS markers limited
  - In real-time case, we may not hit this upper bound all the times
  - Using an optimization in multiple Interest handling (described on next slide)

Multiple Interest Optimization at Forwarder
(Dealing with PIT Scaling Issue)

- **Forward** the second (duplicate) Interest only if receives **with a higher QoS marking** than the one already pending in PIT
  - **Replacing** existing PIT entry with higher QoS marking from the new Interest
    - Aggregation based on highest QoS marker for given content name
  - **Updating** existing PIT entry irrespective of the interface the Interest is received on
    - An efficient PIT design to optimally aggregate the QoS markers is required
    - Design shall be based on hierarchical/ordered set of QoS marking in PIT entry
  - Data to the downstream Interface goes either with its original QoS marking or with a higher QoS marking updated by second (duplicate) Interest
- **Do not forward** the second (duplicate) Interest **with a lower QoS marking** for which an Interest with higher QoS marking is already pending
  - Most likely or not, Data with higher QoS marking shall return faster than the Data with lower QoS marking
  - As a result, a user with lower quality subscription may experience a better response time from the network
    - This is a legit behavior, as ICN is fundamentally designed to optimize the network round-trip time

Forwarder Behavior on Data Arrival

- The arrival of Data packet to satisfy all PIT entries against the content name, in addition to the QoS markers in Data packet
- Two possibilities depending on the type of QoS marker aggregation in PIT
  - If aggregation with the highest QoS marker (PIT replacement) for given content name
    - Data arrival satisfy all the pending Interest irrespective of the received QoS marker
    - Data forwarded to all the Interests recorded in the PIT for given name
  - If aggregation is done with a hierarchical/ordered set of QoS markers
    - Data arrival to satisfy all the pending Interests with QoS marker **<=** the QoS marker in the Data packet
- The hierarchical/ordered set aggregation is more flexible and it performs the Data forwarding close to the original QoS marking

<= : less than or equal to

Where QoS Marker Mutation Might be Useful?

- QoS mutation could be implemented as control against abuse
  - This could be performed by the network (MME/AMF, forwarder) or producer
  - Network override or overwrite the QoS marking set by the client
- Used by forwarder to update the QoS marker in the PIT entry
  - Assuming forwarder uses highest QoS marker based PIT aggregation
- QoS mutation mapping
  - Map from-to when ICN QoS marker needs to be altered
- Some other use cases that may be related to QoS mutation (to be explored)
  - Dynamic traffic shaping and/or rate control to adaptively and intelligently react to and resolve the network traffic problems
  - Fine control of QoS management in real-time streaming application
  - New opportunities to use of AI/ML in the networking

Advantages

- A flexible scheme by virtue of disaggregation of routable name component and non-routable name component
- QoS markers potentially can be designed to achieve both flow classification as well as QoS based scheduling in the network
  - This is a second level design problem
- The independence of routable name component and the QoS marker, does not impact the (FIB) scaling
  - An opportunity to implement QoS sensitive/aware routing/forwarding decisions
- Mutable QoS markers makes it possible to change the QoS between the two router nodes within same domain (intra service provider n/w) or two router nodes across two domains (inter service provider n/w)
  - If we consider a per-hop-behavior in the QoS processing

Summary & Future Work

- An improved QoS mechanism compared to the DSCP based approach
- Disaggregation of routable content name and non-routable, mutable QoS markers provides better flexibility
- Independence between content name and QoS marking makes their evolution much easier and yet bounded to content name keeping with ICN principles
- A potential impact on PIT scaling and an optimization to deal with the problem
  - Number of pending Interests requests in PIT for same content to be normalized around the highest QoS marking (more detailed look required)
- Future plans
  - Evaluate the impact on PIT aggregation and effect of optimization
  - Design a naming scheme/standard for QoS marking
  - Explore if/how QoS marking scheme can also be used for flow classification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