NDN-RTC: Real-Time Videoconferencing over Named Data Networking

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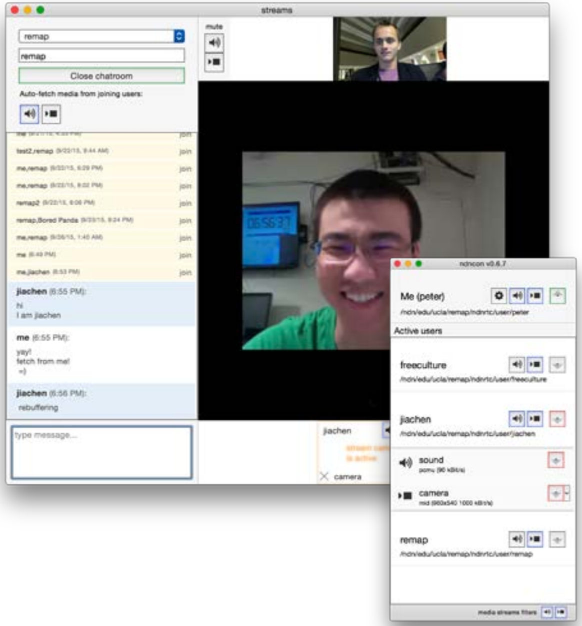
NDN-RTC Project Goals

- Experimental research in low-latency, real-time multimedia communication over NDN
- Functional videoconferencing library+application:
  - Low-latency, interactive data distribution:
    - Multi-party conferences
    - Live broadcasting
  - Data-centric security: schematized trust, name-based access control
  - Wide adoption by NDN community
- Testbed traffic generation and high-load performance testing



Why use NDN for RTC?

- Demonstrate viability of low-latency streaming over NDN
- Generalized approach
  - Explore other possibilities where low-latency fetching can be used
- Inherent network capabilities
  - Mobility
    - Producer provides namespace for published data
    - Consumer needs to know only names for fetching data from the network
  - Scalability
    - No direct coordination by producer

Design Objectives

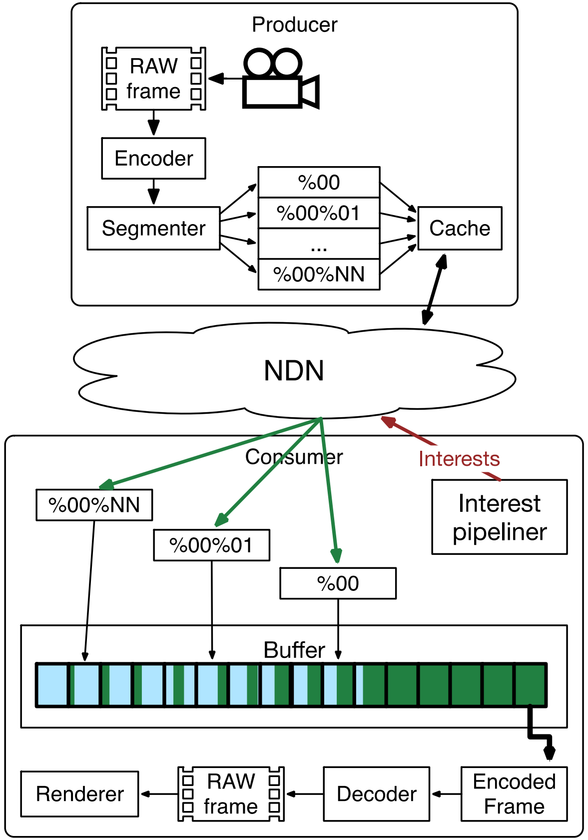
- Achieve low-latency communication

    250-750ms for audio and video

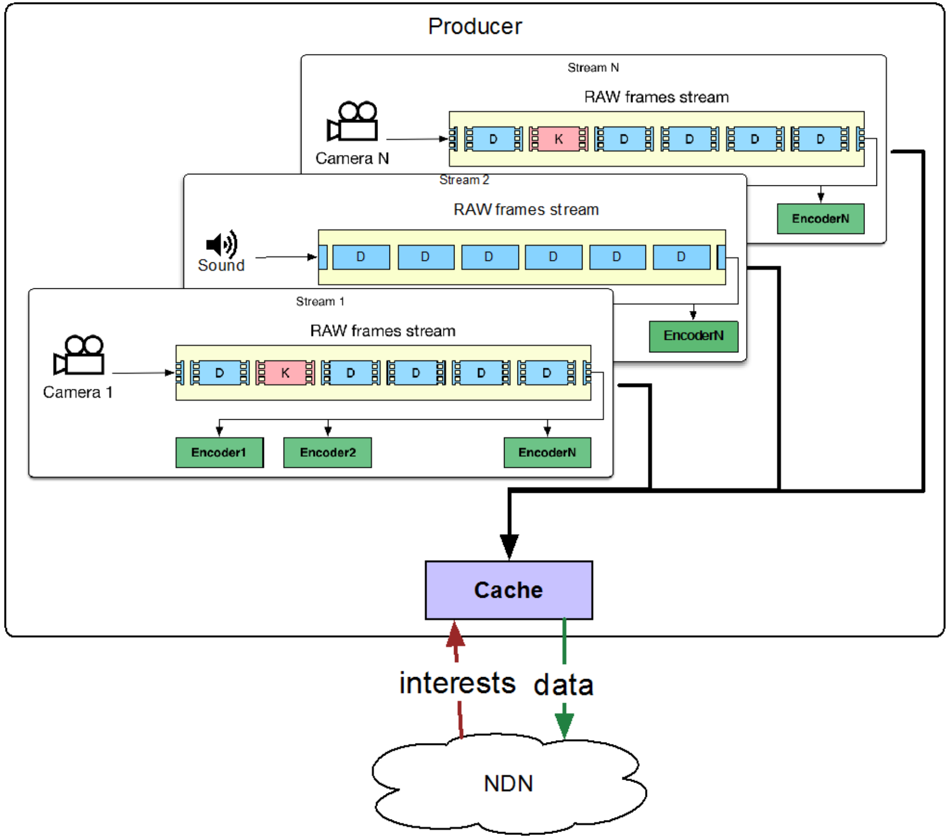
- Straightforward publishing and fetching for multi-party conferences
- Passive producer & cacheability
    - No explicit coordination between producer and consumer
    - Enable exploration of network-supported scaling to high producer-consumer ratios
- Multiple bitrate streams
    - Supported by namespace
    - Enable near-future work on Adaptive Rate Control
- Data verification using existing NDN features

Architecture Overview

- Pull-based approach: complexity shifts to the consumer
- Producer
  - media acquisition & encoding
  - segmenting & naming according to namespace
  - adding segments the the network-aware cache
- Consumer
  - maintain Interests pipeline according to current network conditions
  - track data arrival and buffer level for Interests retransmissions
  - re-assemble segments, buffer, decode & playback



Typical Producer Setup



Application Namespace

Root:

- User prefix (username)

Media streams:

- Media streams (audio/video)
- Streams meta info

Encoding media threads:

- Individual encoding parameters

Frame type:

- **Key** and **Delta** frames in separate branches

Packet:

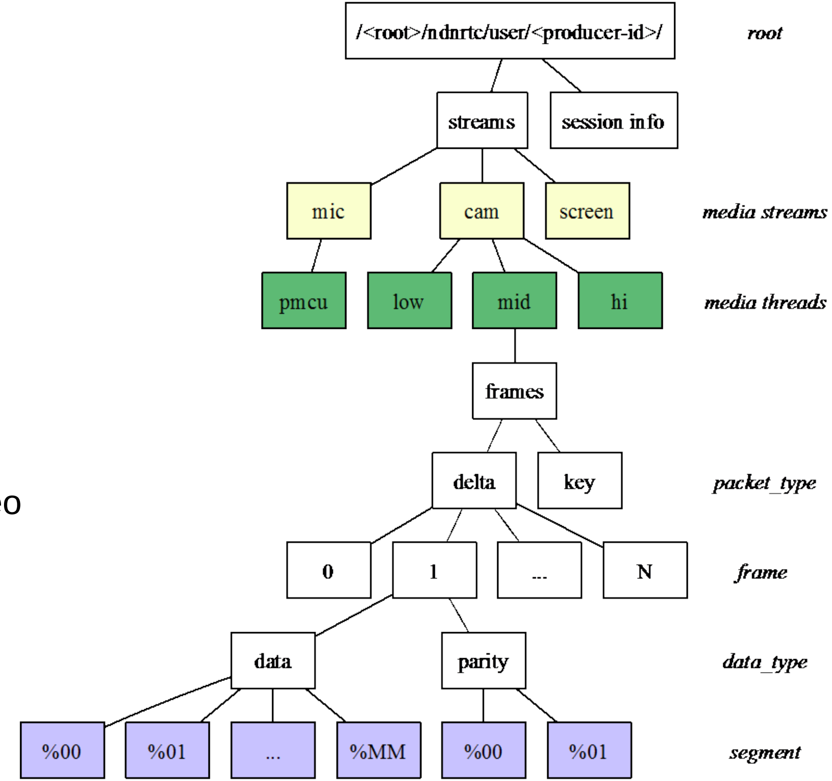
- Individual media packets (audio samples, encoded video frames)

Data type:

- Data and Parity segments in separate branches

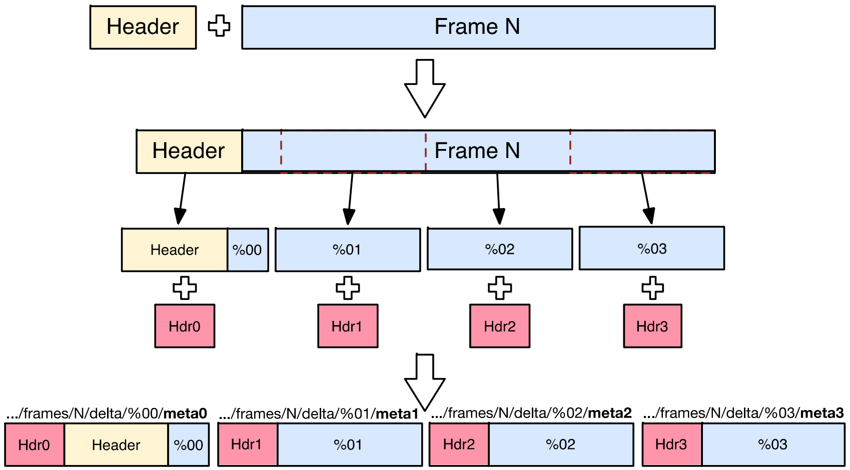
Segments:

- Actual NDN-data objects

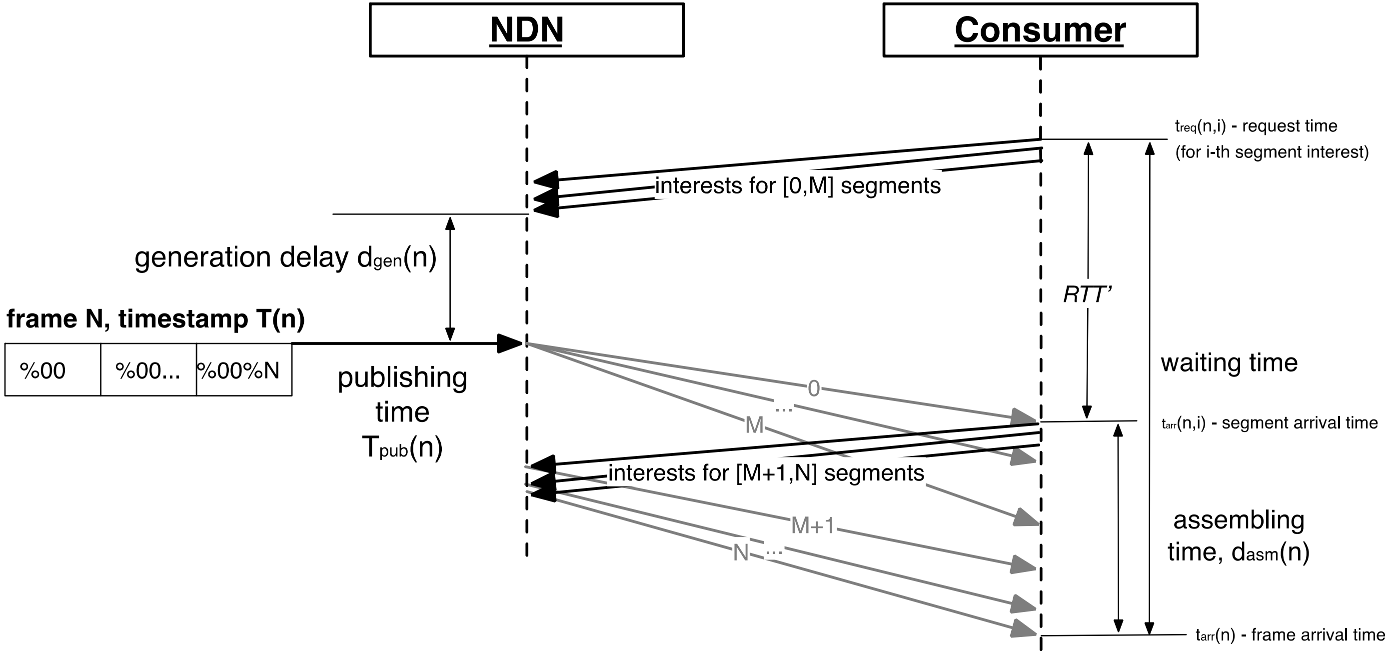


Segmentation & Metadata

- Encoded frames (1Mbps):
  - Key: ~30KB (30 segments)
  - Delta: ~1-6KB (~5 segments)
- Producer stores segments in app cache
  - Segment size - 1000 bytes
  - NDN overhead - ~330-450 bytes
- Metadata
  - Frame-level: encoding info, timestamps
  - Segment-level: generation delay, total segments number, etc.

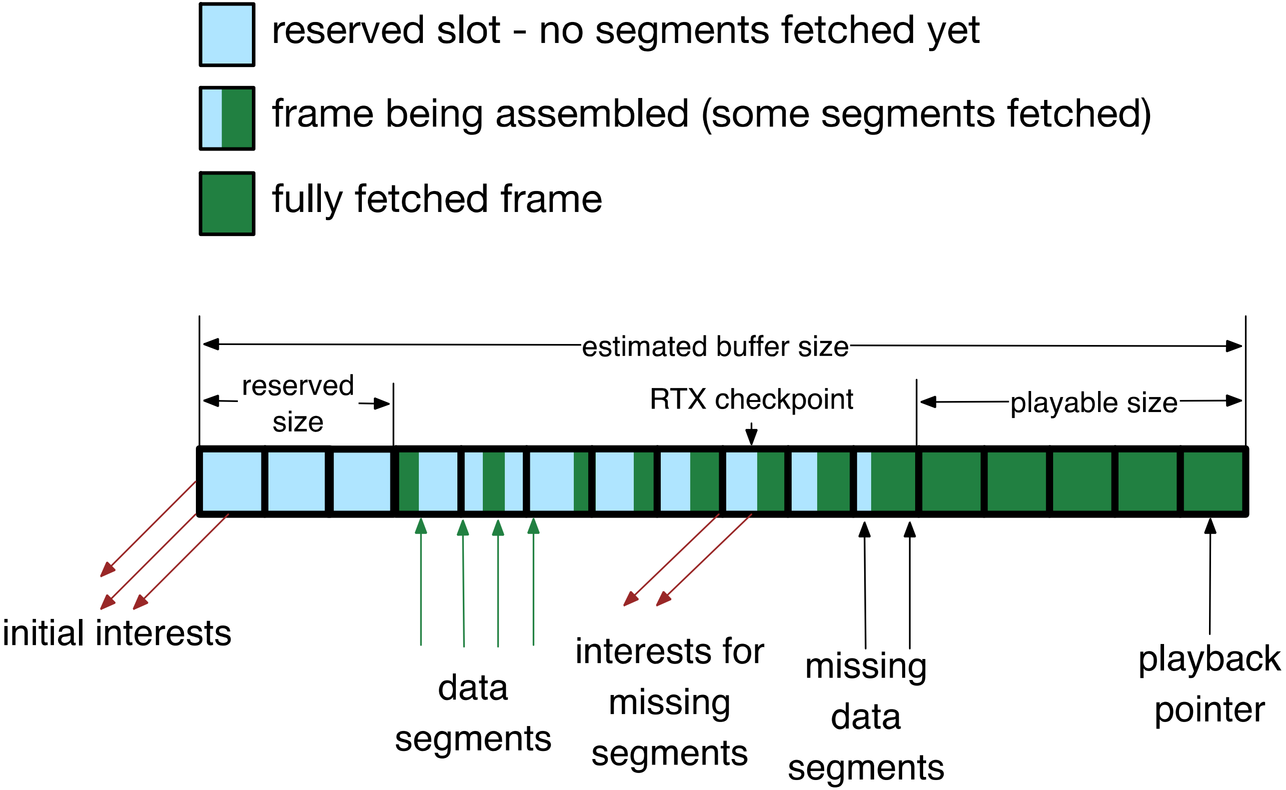


Frame Fetching



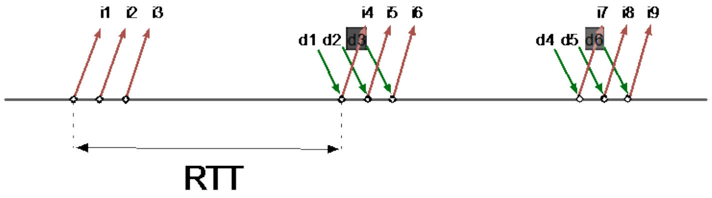
- **Generation delay d_{gen}** – time interval between interest receipt and data generation (*producer-side*)
- **Assembling time d_{asm}** – time needed to fetch all frame segments (*consumer side*)
- ***RTT'*** – consumer-measured round trip time for the interest (*consumer side*)

Interests Pipeline and Retransmissions

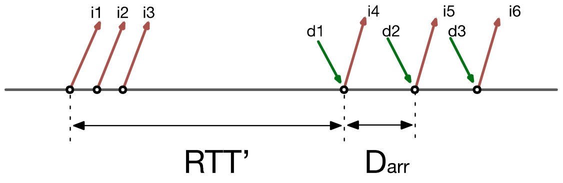


Interest Expression Control

- **Consumer challenge:** ensure acquisition of the latest data without resorting to **direct communication** with the producer and given the presence of **network cache**
- **Observation:** fresh data arrives at producer rate, cached data mimics Interest expression pattern
- **Consumer goal:** receive data at a consistent rate, not reach producer directly



Bursty arrival of stale data copies Interests expression pattern



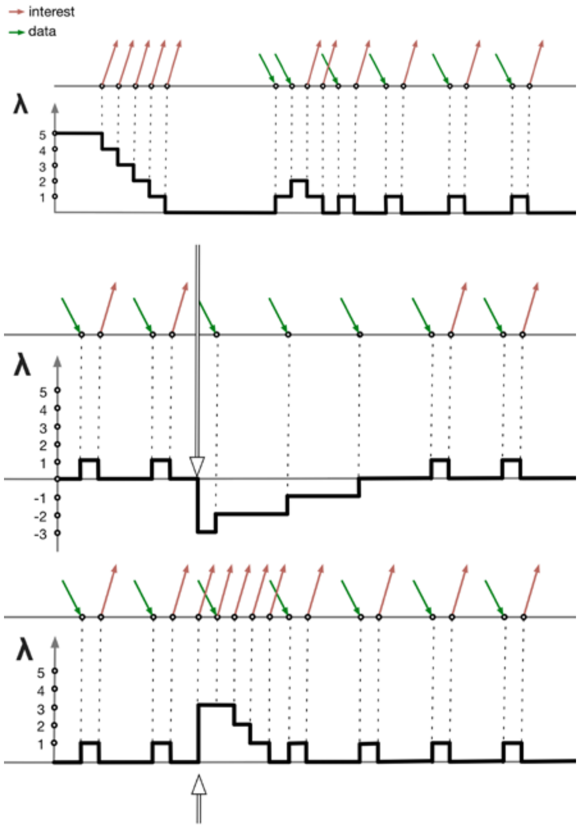
Periodic arrival of fresh data reflects publishing sample rate

Interest Demand

- ***Outstanding Interests*** ensure latest data delivery
- The **minimal number** of outstanding Interests that ensures latest data retrieval defines "***Interest Demand***"
- *Interest Demand (λ)* driven by:
  - DRD (Data Retrieval Delay) – generalized RTT
  - Data inter-arrival delay (producer publishing delay observed by consumer)

Interest Demand = DRD / D_{arr}

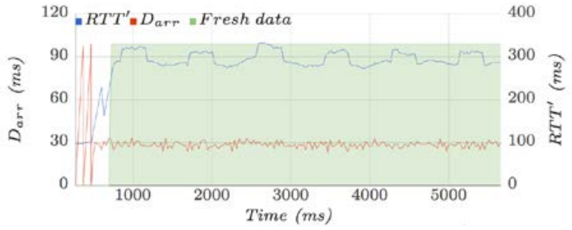
- Consumer changes *Interest Demand* value in order to adjust fetching **aggressiveness**
- Data-driven Interest expression:
  - Quicker response to new network and publishing conditions
  - Faster and more robust bootstrapping



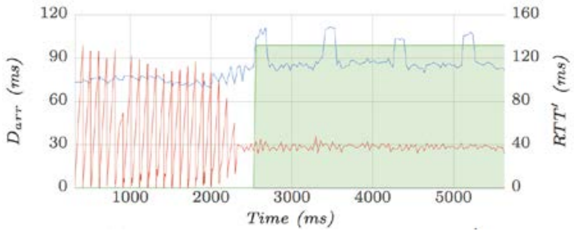
Bootstrapping

- **Bootstrapping mode:** seek through cached data quickly until **freshest data** begin to arrive
- Main indicator: packet inter-arrival delay D_{arr}
- Interest Demand adjustment:
  1. Initialize λ_D and initiate Interest expression
  2. If no fresh data in allocated time – *increase demand*: $\lambda=\lambda+0.5\lambda_D$; $\lambda_D=\lambda_D+0.5\lambda_D$
  3. If cache exhausted – *decrease demand*: $\lambda=\lambda-0.5\lambda_D$; $\lambda_D=\lambda_D-0.5\lambda_D$ **and** wait for one of two outcomes:
     a) *RTT'* decreases and freshest data continues to arrive – repeat step 3
     b) Cached data starts to arrive – restore to the previous λ_D, bootstrapping ended.

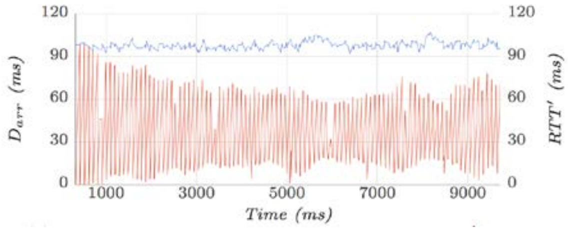
λ=10



λ=4



λ=3



30 FPS; 100ms RTT;

Bootstrapping

Conditions:

- FPS: 30
- GOP: 30
- RTT ~100ms
- λ_{start} =30

Results:

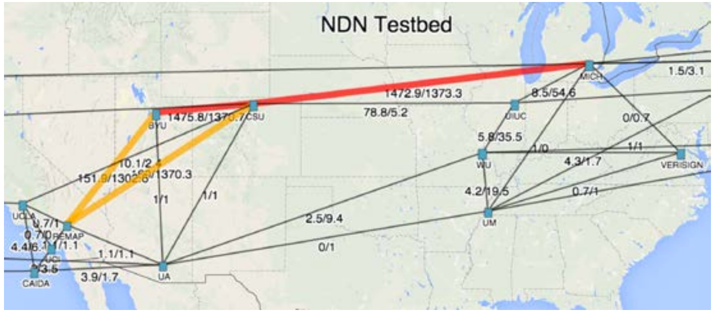
- *RTT'* ~110ms,
- Unstable phase ~700ms, 1600ms
- λ_{final} = 4

Iterative Design Improvements

- Consumer-producer synchronization
  - *Interest demand* allows to adjust fetching aggressiveness of the consumer
  - Consumer reduces number of pending Interests in PIT, thus achieving better synchronization with the Producer
- Streaming performance:
  - Namespace separation of *Key* and *Delta* frames
  - Audio packet bundling
- NFD: early retransmissions strategy
  - App retransmission was suppressed until Interest times out in PIT
  - Varying Interest lifetime is risky when data is not produced yet or network conditions change
  - BestRoute2 strategy allows early app retransmission without giving up Interest lifetimes

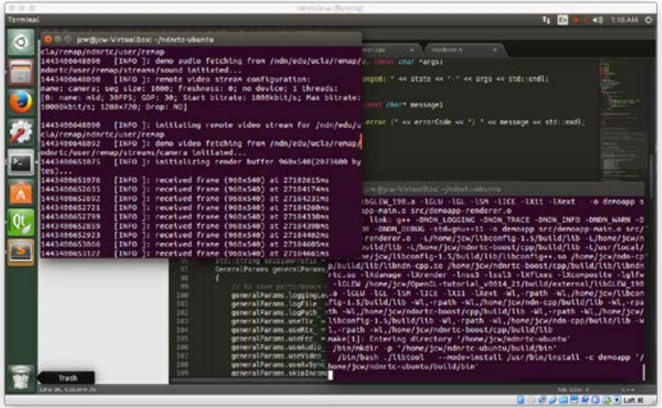
Implementation Details

- C++ library (OS X, Ubuntu)
- WebRTC for audio pipeline
- VP8/9 video encoder
- Forward error correction with OpenFEC
- Open source
  - github.com/remap/ndnrtc
- GUI OS X conferencing app on top of NDN-RTC – *ndncon*
  - github.com/remap/ndncon



Future Work

- Adaptive Rate Control *(in progress)*
- Linux compatible version *(in progress)*
- Ubuntu headless app *(in progress)*
- Further tests
  - multi-party uni- and bi-directional tests *(ongoing)*
  - NFD performance stress tests *(ongoing)*
  - large-scale tests using headless Ubuntu app
- Data authentication and encryption with multi-party support
- Scalable video coding



Challenges

- **How to reduce consumer reaction delay?**
  - No **direct** producer-consumer communication
  - Robust freshest data detection
  - Faster reaction to network conditions
- **How to efficiently encrypt media without losing NDN advantages?**
  - Depends on application objectives – Reformulate conferencing?
  - Leverage broadcast encryption and other schemes
- **How to achieve inter-consumer synchronization?**
  - While preserving no direct communication
  - Consider varying network conditions

Opportunities for Collaboration

- NDN project team plans to use and improve *ndncon*. Help welcome!
- Others can use NDN-RTC library for creating more applications.
  - NDN-RTC repo: github.com/remap/ndnrtc
  - *ndncon* repo: github.com/remap/ndncon
- Deeper research into rate control, interest expression algorithms needed.
- Need to do simulations to look at algorithm performance under various caching conditions, topologies, and use cases.

Thank you!

Q&A

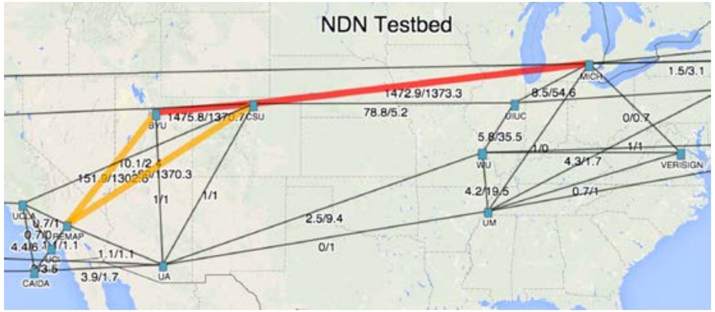
Additional Slides

Example NDN-RTC-driven Improvements

- NFD: Revised retransmissions strategy
  - App retransmission was suppressed until Interest times out in PIT
  - Varying Interest lifetime is risky when data is not produced yet or network conditions change
  - BestRoute2 strategy allows early app retransmission without giving up Interest lifetimes
- NDN-CCL: Library support for app-level PIT
  - Common low-latency case: **handle Interests that arrive before data is ready**
  - Need to store Interests in producer-side PIT
  - Same approached used in OpenPTrack real-time person-tracking
- Testbed/NFD: Performance stress-tests (ongoing)
  - 3-9Mbit/sec data streams per producer
  - 9Mbit/sec: ~1000 Interest/sec, ~900 data segments/sec
  - Traffic generator for the testbed

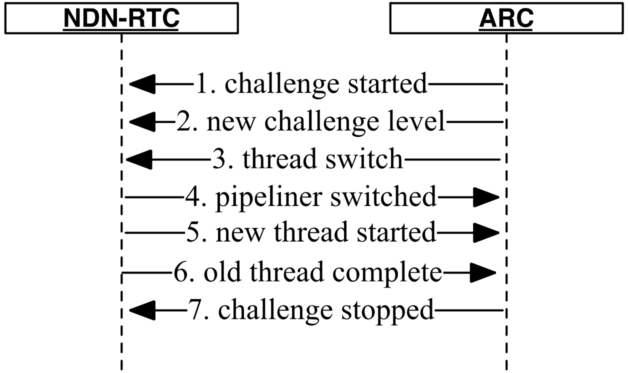
Design & Development Progress

- Design
  - “*Interest Demand*” concept introduction
  - Audio packet bundling
- Implementation
  - Desktop GUI application *ndncon*
    - group chats (ChronoChat2013)
    - automatic user discovery (ChronoSync2013)
    - screen sharing
  - Thread optimization
    - single-threaded architecture, decreased CPU
  - Asynchronous logging
  - Automated test environment (local testbed, NDN testbed)
  - **Ported to Ubuntu**
    - special thanks to **Luca Muscariello** (Orange), **Zhehao Wang** (UCLA)



Adaptive Rate Control

- Collaboration with Panasonic R&D department
- Established development plan:
  - NDN-RTC modifications, REMAP - **October 2015**
  - ARC implementation[1], Panasonic - **November 2015**
  - Early tests - **December 2015**
  - Full tests – **January-February 2016**
  - Completion – **March 2016**
- Implementation details[2]
  - Gapless stream switching
  - Challenging Interests for bandwidth probing
  - Ongoing monitoring of intrinsic network parameters (DRD, D_{arr}, etc.)



[1] Takahiro, Y. et al. **Consumer driven Adaptive Rate Control for Real-time Video Streaming in Named Data Networking.** *To be presented at Internet Conference 2015, October*

[2] Ohnishi, R. et al. **Adaptive Rate Control integration for NDN-RTC.** *NDNComm 2015, Poster session*