MONROE: A Distributed Platform for Mobile Broadband Measurements

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Mobile broadband (MBB) networks

- Underpins a lot of vital operations of the modern society
Mobile broadband (MBB) networks

- The popularity of mobile devices combined with high-capacity 3G and 4G mobile networks, has radically changed the way most people access and use the Internet.
Mobile Ecosystem

- Very complex!
- Theory does not tell it all. Hard to isolate different layers.
- Need for objective end-to-end measurements!
MONROE: a unique platform for measurements and experiments in operational MBB networks

- Design, build and operate an open, European-scale, and flexible platform to run experiments on operational 3G/4G Mobile Broadband networks with WiFi connectivity

- Use the platform for:
  - identification of key MBB performance parameters, thus enabling accurate, realistic, persistent and meaningful monitoring and performance assessment
  - examination and evaluation of innovative protocols and services for MBB networks
MONROE

- Coverage to 4 European Countries (Norway, Sweden, Spain, Italy)
- Nodes on buses, trains and trucks
  - Impact of mobility
- 3MBB operators and WiFi
  - Experimenting on different access technologies
  - Explore new ways of combining them to increase performance and robustness
MONROE Nodes

• Small, affordable, robust, sufficiently powerful HW supporting the mainline Linux kernel.
  – Single Board Computers (SBCs) due to size and price constraints

• Selected: PcEngines APU
  – 1Ghz 64 bit quad core processor, 4GB of RAM, 16GB HDD.
  – 3 PCI-e slots, two of which support 3G/4G modems
Initial Node Design

- APU
- Yepkit self-powered USB hub
- 3 USB-based CAT4 MF910 MiFis
- 1 WiFi card
Experience

• APUs proved to be very stable
• MiFis proved more challenging than expected:
  – A forced update to the firmware made all our MiFis became inaccessible
  – MiFis themselves were prone to enter a working state (transparent PPP) from which we could only restore them by draining their batteries, or perform a manual reboot by pushing the power button
  – Some of the MiFis showed clear signs of bloated batteries
Final Node Design

• Dual-APU
• Head: 2 PCI-e CAT6 modems
• Tail: 1 PCI-e CAT6 modem and a Wifi card
MONROE Software Ecosystem

Experimentation Enablers
- Connectivity measurements (ping)
- Metadata Collector
- Tstat

OMQ Metadata Multicast
- Scheduler Client

Watchdog
- BootOS

Maintenance

Internal NAT Function
- wwan0
- wwan1
- wwan2

Users’ Experiments

host Namespace
- Routing Daemon
- Device Listener
- Network Monitor

Management

MONROE Namespace

docker
Internal NAT Function

• MONROE namespace ensures the minimum impact of user experiments gone wrong
• For each physical interface, a virtualized ethernet (veth), interface pair is created
  – one end in host namespace and one end in MONROE namespace
• Routing rules are added in the network namespace to allow routing by interface.
• Define internal internal Network Address Translation (NAT) function to allow communication between host namespace and MONROE network namespace
• Use iptables NAT masquerading rules in the host namespace to configure the NAT function.
Docker Virtualization

• Each experiment runs inside a virtualized environment (Docker container) to ensure separation and containment of processes

• Docker containers are based on a layered file system
  – Default base image for the experiment containers integrates the base operating system installation with default tools
  – Containers provide just the contents that are unique for the particular experiment
    • significantly reducing the download and deployment time overhead and accountable traffic volume

• Experiments running inside a container
  – have access to the experimental network interfaces
  – can read and write on their own file system, overlaid over that of the base MONROE image
  – write their results to (e.g., /MONROE/results/) to be automatically transferred to the MONROE servers
Information Flow

MONROE Nodes
- Scheduler Status
- System Status
- GPS
- Modem

Metadata Exporter

ZMQ

Experiment Containers

(Meta)data Subscriber

(User Access and Scheduling) Web Interface

Experiment Deployment

Experimental Results

(Meta)data DB
MONROE Backend

User Access and Scheduling System

Management and Maintenance

MONROE Measurement Responder

MONROE Experiments

Core Components

tStat

External User's Experiments

MONROE Experiments

NODE

REMOTE

REPOSITORY

MONROE

DATA IMPORTER

MONROEDB

MONROE VISUALIZATION

Inventory DB for Maintenance and Operations

Scheduling DB
(quotas, current sched, past sched.)

OPEN DATA

USERS' STORAGE

EXTERNAL

- by thinking constantly about it
User access

Federation with FIRE/FIRE+
- User access and node utilization managed according to a standardized and unified approach
  - Reuse Fed4FIRE open SW
  - GENI API v.3
  - REST as parallel API for development
MONROE Web Interface: Resources

List of Resources
- Show only nodes that can execute experiments

Locations:
- Norway
  - Norway-NSB (trains)
  - Sweden
  - Sweden-VTAB (buses)
  - Italy
  - Italy-GTT (buses)
  - Italy-WSYS (trucks)
  - Spain

Node types:
- Deployed
- Testing

Node models:
- apu1d4
- apu2d4
- others

Total nodes: 441
Number of nodes after filtering: 39

Last updated: Sun Jun 18 2017 00:20:26 GMT+0100 (IST)

<table>
<thead>
<tr>
<th>ID</th>
<th>Status</th>
<th>Type</th>
<th>Heart beat</th>
<th>Project</th>
<th>Hostname</th>
<th>Model</th>
<th>Location</th>
<th>Graphs</th>
<th>Interface 1</th>
<th>Interface 2</th>
<th>Interface 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>Active</td>
<td>Deployed</td>
<td>Sun Jun 18 2017 00:19:56 GMT+0100 (IST)</td>
<td>Norway</td>
<td>Monroe0000db94007a4</td>
<td>apu1d4</td>
<td>Maps</td>
<td>Visz</td>
<td>24202 (Telenor) 0 bytes / 50.00 GiB</td>
<td>24201 (Telenor) 46.57 GiB / 50.00 GiB</td>
<td>24201 (Telenor) 46.57 GiB / 50.00 GiB</td>
</tr>
</tbody>
</table>
MONROE Web Interface: New

New Experiment

Description

- Name: Name of the experiment
- Script: Docker pull URL
- Parameters: "key":number,"key":"string"  JSON-style user options to be passed to the container

Requirements

Number of nodes: 1  Duration: 300 seconds

Select nodes either using filters or providing a list of IDs:

Node filters:

Countries (select to restrict):
- Norway
- Norway-NSB (trains)
- Sweden
- Sweden-VTAB (buses)

Node type: Deployed

Explicit node selection:

Node IDs: List of comma-separated specific nodes to use in the experiment.

Clear
### Experiments for user Ozgu Alay (ID = 18)

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Tasks</th>
<th>Start</th>
<th>Stop</th>
<th>Ongoing</th>
<th>Successful</th>
</tr>
</thead>
<tbody>
<tr>
<td>8391</td>
<td>web_trial_docker</td>
<td>2</td>
<td>Sat Jun 17 2017 19:30:49 GMT+0100 (IST)</td>
<td>Sat Jun 17 2017 19:40:49 GMT+0100 (IST)</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Node types:**
- Number of executions: 2
- Finished: 2
- Stopped: 0
- Failed: 0
- Canceled: 0
- Aborted: 0
- Remaining: 0

**Individual schedules: 2**

<table>
<thead>
<tr>
<th>Sched</th>
<th>Node</th>
<th>Status</th>
<th>Start</th>
<th>Stop</th>
<th>Shared</th>
<th>Storage</th>
<th>Traffic quota</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>217438</td>
<td>461</td>
<td>Finished</td>
<td>Sat Jun 17 2017 19:30:49 GMT+0100 (IST)</td>
<td>Sat Jun 17 2017 19:40:49 GMT+0100 (IST)</td>
<td>0</td>
<td>256.00 MIB</td>
<td>200.00 MIB</td>
<td>download</td>
</tr>
</tbody>
</table>

To connect to your experiment container:

```
ssh -o StrictHostKeyChecking=no -o UserKnownHostsFile=/dev/null -i
```

<table>
<thead>
<tr>
<th>Sched</th>
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<td>217439</td>
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<td>Finished</td>
<td>Sat Jun 17 2017 19:30:49 GMT+0100 (IST)</td>
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<td>0</td>
<td>256.00 MIB</td>
<td>200.00 MIB</td>
<td>download</td>
</tr>
</tbody>
</table>

To connect to your experiment container:
**Node(s)**

Scheduler client (Marvin-ctlD)
- deploy containers
- start containers
- stop containers
- report task status
- report resource usage

**Aggregation Manager (AM)** (Marvin-d Scheduler)
- manage calendar
- Reservation API
- Manage quotas
- Keep history

**Scheduling DB (SQLite)**

- send heartbeat, status, pull schedule (REST API)
- register and update in inventory
- setup autotunnel ssh control channel

**F4F certified user**

- User access
- SFA API
- REST/GENI API
- pull (REST API)

- Inventory
- Inv DB

- **Scheduling**

- pull (REST API)
Scheduling policies

• Schedule an experiment on $n$ nodes of type $t$ at given time (start, end)
  – type selectors: deployed, testing, mobile, static, country $X$, operator $Y$

• Only one active measurement experiment may run at a time (marked as exclusive)

• Several passive experiments may run at a time

• Quotas enforced in terms of storage, volume of data exchanged

• Priority translates into pre-booking periods, else FCFS.
Data and Metadata Importer

• Local files are exported to the remote repository
  – Connection status to the remote repository:
    • Connection exists:
      Every 2 minutes this file rsync'ed
    • Connection does not exist:
      Continue local logging until connection comes up or disk is 90% full.

• On the remote repository
  – Parse and injected into the DB every 20 secs
  – Daily backup (with compressed JSON files)
MONROE DB

• Used to store:
  – Measurements (RTT, throughput, packet loss, DL time, ....)
  – Metadata (signal strength, connectivity type, GPS, ...)

• For data and metadata use a big data solution
  – Friendly for parsing long time series
  – Scales much better than a relational database

• Data accessible with tools specialized for Big Data analysis
Experimentation Process

Experiment design phase
- Design experiment
- Configure container for experiment
- Store container in repository

Testing phase
- Schedule container in a testing node
- Deployment + test
- MONROE certification

Experimentation phase
- Schedule experiment
- Deployment / execution
- Retrieval of results (per node / per schedule)
MONROE Measurements and Experiments

Users

Operators

Business

MBB Metrics Applications Protocols

Research

Regulators

- by thinking constantly about it
MONROE Use Cases

Key MBB Metrics
- Network tomography
- Traffic analysis with Tstat

Application Performance
- Video applications
- Web services

Protocol Innovation
- Internet Path Support
- Multipath protocols
- Traffic Offloading
Use Case 1: KEY MBB Parameters

*Performance assessment and monitoring of mobile broadband (MBB) networks*

- Network Tomography: Performance and Reliability Parameters
  - Latency, packet loss, bandwidth, etc...
- Traffic analysis
  - Monitor and report live traffic statistics
- Route analytics: Network Topology Inference / Analysis
  - Path dynamics, Internet routing data, prefix geolocation
Building reliable coverage maps

- Built coverage maps of different operators based on the rich modem metadata

- “Profiling mobile broadband coverage”, Traffic Monitoring and Analysis (TMA), 2016 (best paper award)
- “ZipWeave: towards efficient and reliable measurement based mobile coverage maps”, in INFOCOM 2017
Tstat monitoring

- Deployed Tstat on all MONROE nodes
- Analyzed the log files together with the metadata, used Tstat passive traces to identify the proxies in MBB’s infrastructure

```
<table>
<thead>
<tr>
<th>Country</th>
<th>Operator</th>
<th>Private IP &amp; NAT</th>
<th>$\overline{G}$ mismatch on port 80</th>
<th>L4 Mangling</th>
<th>Connection (percentage) Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>op0</td>
<td>Yes</td>
<td>Yes*</td>
<td>All</td>
<td>3G (0.46), 4G (0.54)</td>
</tr>
<tr>
<td></td>
<td>op1</td>
<td>Yes*</td>
<td>Yes</td>
<td>All</td>
<td>3G (0.15), 4G (0.85)</td>
</tr>
<tr>
<td></td>
<td>op2</td>
<td>No</td>
<td>Yes</td>
<td>All</td>
<td>2G (&lt; 0.01), 3G (0.08), 4G (0.92)</td>
</tr>
<tr>
<td>Sweden</td>
<td>op0</td>
<td>Yes*</td>
<td>Yes*</td>
<td>All</td>
<td>4G (100)</td>
</tr>
<tr>
<td></td>
<td>op1</td>
<td>No</td>
<td>Yes</td>
<td>All</td>
<td>3G (&lt; 0.01), 4G (0.99)</td>
</tr>
<tr>
<td></td>
<td>op2</td>
<td>No</td>
<td>Yes</td>
<td>All</td>
<td>3G (0.37), 4G (0.63)</td>
</tr>
<tr>
<td>Spain</td>
<td>op0</td>
<td>Yes</td>
<td>No</td>
<td>All</td>
<td>4G (100)</td>
</tr>
<tr>
<td></td>
<td>op1</td>
<td>Yes</td>
<td>No</td>
<td>All</td>
<td>3G (0.16), 4G (0.84)</td>
</tr>
<tr>
<td></td>
<td>op2</td>
<td>No</td>
<td>Yes</td>
<td>All</td>
<td>3G (0.07), 4G (0.93)</td>
</tr>
<tr>
<td>Norway</td>
<td>op0</td>
<td>No</td>
<td>Yes*</td>
<td>All</td>
<td>4G (100)</td>
</tr>
<tr>
<td></td>
<td>op1</td>
<td>Yes*</td>
<td>Yes*</td>
<td>All</td>
<td>3G (0.08), 4G (0.92)</td>
</tr>
</tbody>
</table>
```

Use Case 2: Application Performance

*Service-oriented measurements*

- Performance Measurement for Video on Demand and Video Conferencing Systems
- Performance measurements of Web traffic
- Assessment of Online Gaming performance
- Effect of the background traffic on the application performance
- Study how Quality of Experience (QoE) can be estimated from objective metrics
Web Performance

• Developed a web performance measurement tool
• Analyzed web performance over different operators as well as over different protocols
Video Streaming with DASH

• Developed a DASH measurement tool
• Analyzed the performance of different DASH rate-adaptation algorithms over different operators
Use Case 3: Novel Services and Protocols

*Examination and evaluation of innovative protocols and services for MBB networks*

- Evaluation of path support for MPTCP, ECN, TCP Fast Open, etc.
- Protocol Performance Optimizations
- Traffic offloading between MBB and WIFI
- Multipath Performance Measurements
Path support for IP and TCP

- Test path support for IP and TCP, e.g., MPTCP, ECN, TCP Fast Open
- Customized PATHspider to measure across multiple paths
- We carried out a large scale path support measurement campaign over mobile networks

“Path transparency measurements from the mobile edge with PATHspider”, accepted by IEEE/IFIP MNM Workshop 2017
“Exploring DSCP modification pathologies in mobile edge networks”, accepted by IEEE/IFIP MNM Workshop 2017
MPTCP: intelligent interface selection

- Implemented NEAT transport architecture in MONROE
- Experiments over MPTCP
- Uses metadata to make a decision on the paths and selects them accordingly

Relative download performance using MPTCP with different primary path configuration and NEAT

“A NEAT approach to mobile communication”, accepted by SIGCOMM 2017, MobiArch workshop