National Institute of
Information and Communications Technology

Research Issues toward the Next Generation of Mobile Networks in NICT

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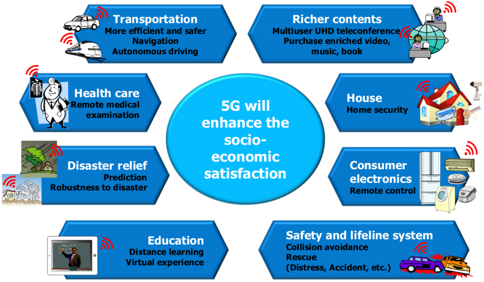
1 December 2015, Aizu

Outline

The Fifth Generation of Mobile Network

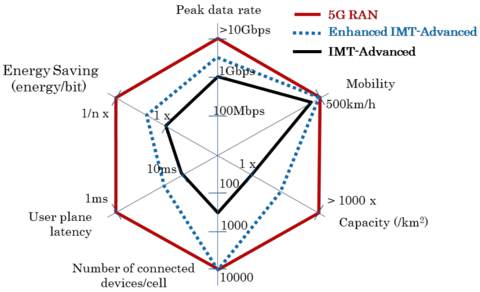


Source: Association of Radio Industries and Businesses (ARIB) whitepaper

5G by 2020

- Enabling new applications/industries
- Empowering new user experience
- Reasonable cost

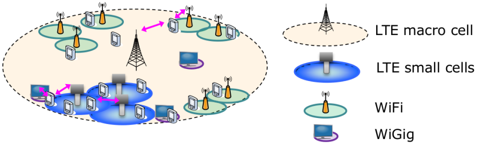
5G KPIs



Source: ARIB whitepaper

- Novel requirements of Key Performance Indicators (KPIs)
- User-centric requirement

Common In 5G



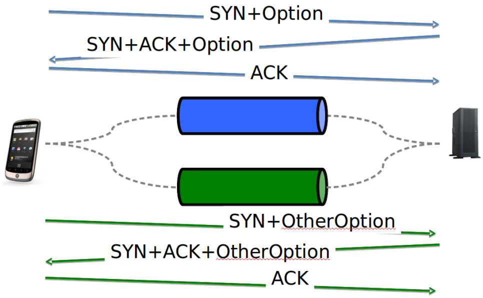
Source: ARIB whitepaper

- A 5G device commonly has multiple wireless interfaces
  - Wi-Fi, LTE, mmWave, etc.
- Heterogeneous networks (i.e., a 5G within the coverages of several base stations)
  - Same or different technologies
- Potentially providing sufficient networking resources
  - The KPIs are promisingly achievable by various wireless technologies

Requirements

- Flexible methods to access and share 5G accessible networks
- Efficient use of 5G resources
- User centric design along with system centric design

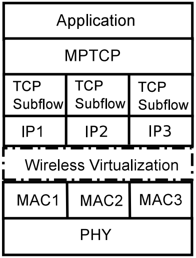
Link Aggregation using Multipath TCP



MPTCP

- Standardized by IETF
- Concurrent TCP subflows via different end-to-end paths
- Three way handshaking (SYNC, SYNC/ACK, ACK) with the MP_CAPABLE option
- Flexibly adding/deleting paths
- Available on Linux kernel, Android phone, Apple iPhone

Example of combining MPTCP in Wi-Fi

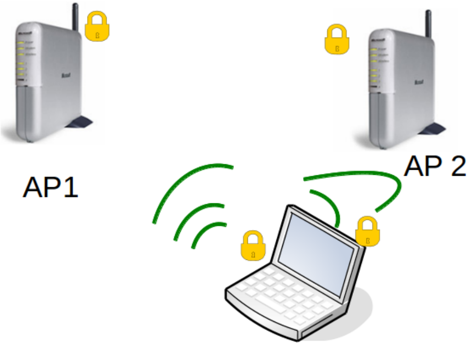


WiPoMu[1]

- Require the minimum change on Wi-Fi client
- Software-based cross-layer solution
- Building upon Wi-Fi virtualization, Policy Routing, and MPTCP

[1] **Kien Nguyen** et al. *"A Cross-layer Approach for Improving WiFi Performance,"* IEEE IWCMC 2014

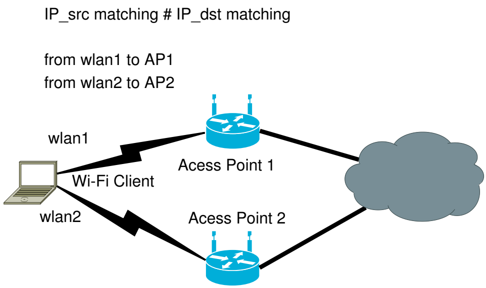
Wi-Fi Virtualization



Multiple logical Wi-Fi interfaces on a physical one

- Managed by a middle layer between MAC and IP
- Transparent with the physical layer
- First available on Windows, then popular in Linux and others

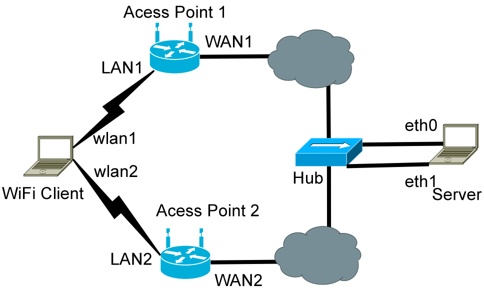
Policy Routing



Source Based Routing

- Keeping the correct operation of traffic flows in WiPoMu
- Implementation using iproute
- Packets with different IP sources following different paths

Prototyping and Evaluation in Indoor Testbed



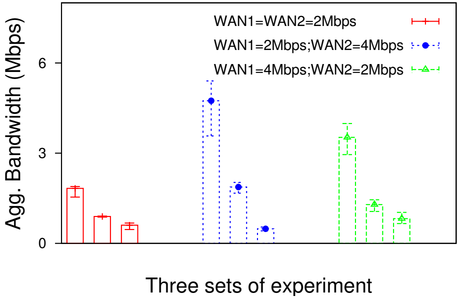
- A WiPoMu client connects to a server via two paths over Internet
- The delay and bandwidth parameters are emulated on Linux machine
- For the real home network, the server is the iperf at multipath-tcp.org

Experimental Setup

Network parameters

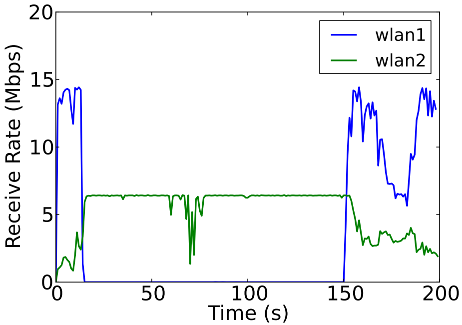
Device	Interface	Address
WiFi Client	wlan1	192.168.11.3/24
	wlan2	192.168.1.100/24
Server	eth0	10.0.11.100/24
	eth1	10.0.1.100/24
AP1	LAN1	192.168.11.1
	WAN1	10.0.11.1
AP2	LAN2	192.168.1.1
	WAN2	10.0.1.1

Improving backhaul throughput



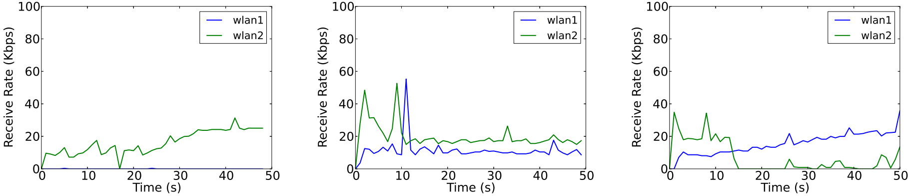
- Three sets of experiments with different network settings
- The left-most one is WiPoMu; The middle and the righ-most ones are the normal Wi-Fi
- The aggregation of bandwidth has been shown

Seamless handover



- Failures happen on the path1, the traffic is automatically switched
- Seamless handover or soft handover has been achieved

WiPoMu in real home networks



Running over Internet

- The left figure shows the case of using Wi-Fi
- The middle figure shows WiPoMu's aggregation
- The right figure shows WiPoMu's soft handover

5G Access Network

- Proliferation of devices (i.e., densification)
- Various (evolving, new) applications
- Novel QoS/QoE requirements
  - low latency
  - high throughput
  - high reliability

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  - high throughput
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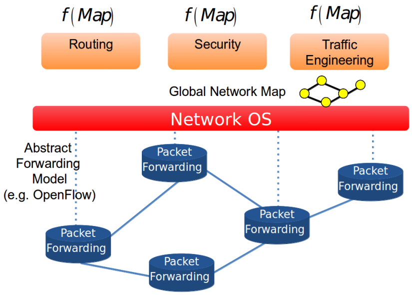
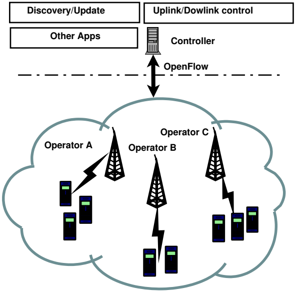
Software Defined Networking (SDN) is a fast evolving technology toward the requirements

SDN



- A Network Operating System (NOS) with a global view of network controls data planes via OpenFlow protocol
  - Relying on a decouple of data and control planes
- SDN provides an easier way to manage and automate networks
- SDN is successfully evolved and deployed in wired networks (e.g., Google's WANs)

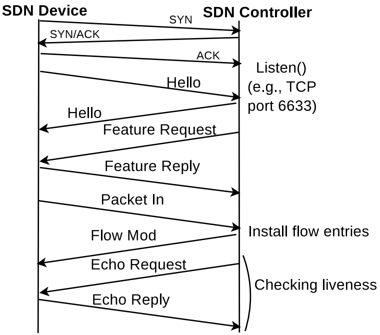
Software Defined Wireless Access Network



SDWAN

- There are many proposals of SDWANs
  - Aiming to cope the scalability, QoS requirements
  - The SDN devices could be mobile devices, L2/L3 switches, etc.
- The major bottleneck: the control (i.e., OpenFlow) channel

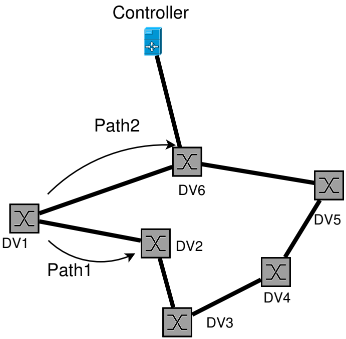
The standard OpenFlow in SDWAN

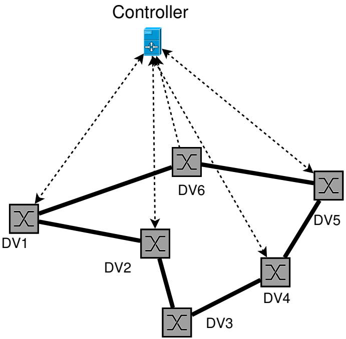


sOF

- Single path communication required TCP/IP connections
- May cause serious problems under failure
  - Fail standalone mode
  - Fail secure mode

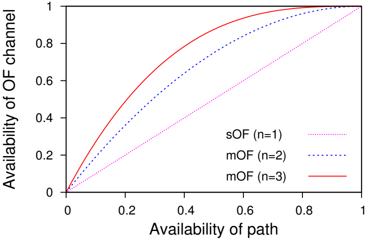
OpenFlow traffic in SDWAN





- Diverse physical deployments for OpenFlow traffic
- Inband, out-of-band
- Or mix that is not well defined in the standard

Multipath for Robustness



Availability

- Let 's denote the average availability of the path i as A_i with the mean of uptime, downtime m_i^{up}, m_i^{down} $A_i = \frac{m_i^{up}}{m_i^{up}+m_i^{down}}$
- If the OpenFlow traffic is on multiple paths, the availability becomes $A_{OF} = 1 - \prod_{i=1}^{n}(1 - A_i)$
- Potentially increasing throughput

Available multipath technologies

- Layer 2
  - 802.1AX
  - TRILL (Transparent Interconnection of Lots of Links)
  - SPB (Shortest Path Bridging)

- Layer 3: ECMP (Equal Cost Multiple Paths)

Available multipath technologies

- Layer 2
  - 802.1AX
  - TRILL (Transparent Interconnection of Lots of Links)
  - SPB (Shortest Path Bridging)
- Layer 3: ECMP (Equal Cost Multiple Paths)

They are suitable with a part of the SDWANs due to the mix deployment

Multipath TCP (reminder)

- A transport layer (e.g., Layer 4) solution
- Overcome the requirements of suitability both for SDWAN and OpenFlow
  - MPTCP works wherever TCP does
- MPTCP is available on popular platforms (e.g., iOS, Android, Linux, etc.)

mOpenFlow[2]

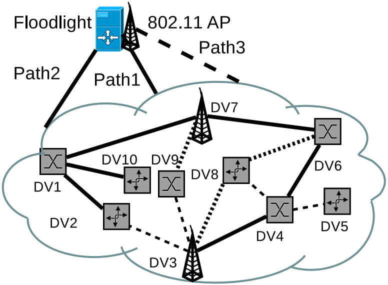
- Initializing connections as MPTCP
  - SYNC, SYNC/ACK, ACK
  - Checking MPTCP-capable option
  - Discovering paths

- Conveying the OpenFlow traffic
  - All or a subset of the available paths
  - One path and other for protection

- Enhancing throughput and robustness of the OpenFlow channel

[2] **Kien Nguyen** et al. *'A Scalable and Robust OpenFlow Channel for Software Defined Wireless Access Networks'*, IEEE VTC-Fall 2015

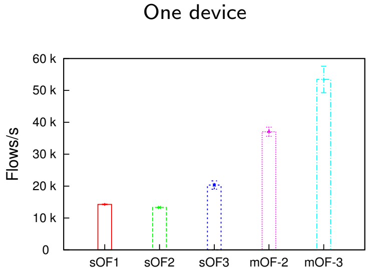
Experimental Setup

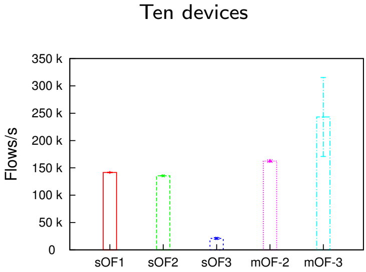


Emulated SDWAN

- Floodlight controller and cbench-generated devices
- Three paths are available between the SDN devices and controller
  - Path1, Path2: wired connections
  - Path3: wireless
- Using cbench (i.e., a SDN benchmarking tool; throughput mode and latency mode)

Scalability Evaluation



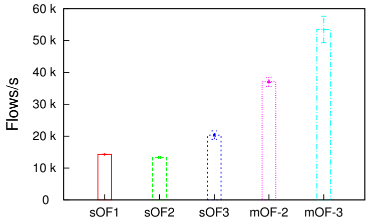


Scalability

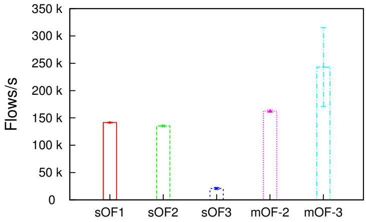
- Using the throughput mode of cbench
- Comparing throughput of the standard channel (sOF) and mOF in one device and ten device scenarios

Scalability Evaluation

One device



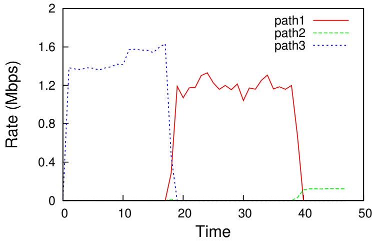
Ten devices



Scalability

- Using the throughput mode of cbench
- Comparing throughput of the standard channel (sOF) and mOF in one device and ten device scenarios
- mOpenFlow outperforms the standard one

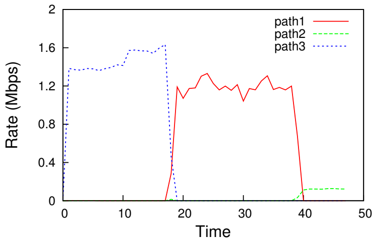
Robustness against failure



Path failure in one device scenario

- Using the latency mode of cbench
- Observing the variation of traffic over three paths that experience failures

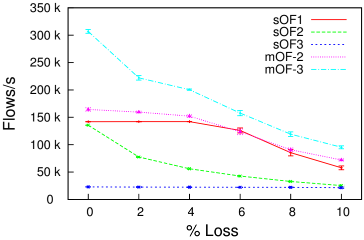
Robustness against failure



Path failure in one device scenario

- Using the latency mode of cbench
- Observing the variation of traffic over three paths that experience failures
- mOpenFlow successfully achieves soft switchover

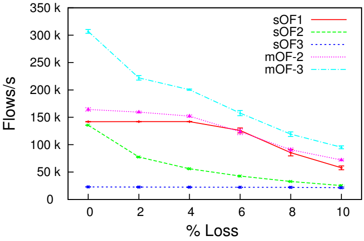
Robustness in lossy environment



Loss resilience

- Using the throughput mode but introducing loss to paths

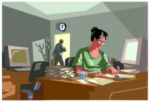
Robustness in lossy environment



Loss resilience

- Using the throughput mode but introducing loss to paths
- mOpenFlow is more loss-resilient than the standard channel

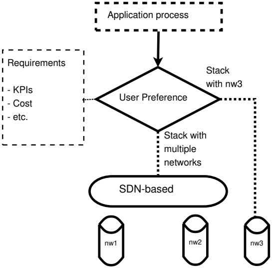
User centric




User centric design

- Diversification of 5G users
- Users actively involve in accessing and sharing Internet connection
  - Capable of selecting the suitable networks
  - Capable of sharing the connections

A user-centric design

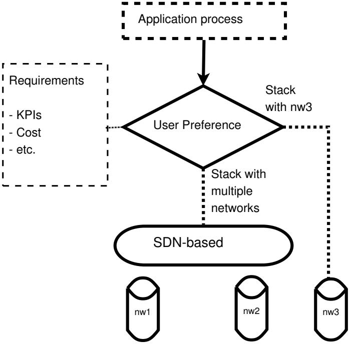


User-centric Software Defined platform (USD)[3]

- Introduce an user-centric module (i.e., user preference)
  - Interface with each application process based on user preference
  - Drive application processes to multiple networking stacks
  - Select suitable interface based on user expectation
- Software-based (i.e., virtualziation)

[3] **Kien Nguyen** et al. *"USD: a User-centric Software Defined Platform for 5G Mobile Devices,"* EAI SDWNCT 2015

USD



- Each networking stack uses either virtual or physical wireless interfaces
- Efficiently utilizing networking resources
  - SDN-based approach to exploit multiple networks
  - Bypassing the disadvantages of state-of-the-art SDN by using an extra interface

User-centric function

- Requiring interactions with users
  - Protactively or reactively based on users' background
- Support users with different technical background
  - Transparent with novice users
  - Fully controllable with expert users
- The simplest form of this module
  - Own decision by expert users

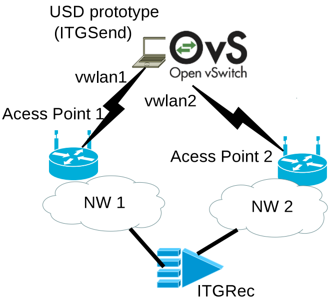
Implementation challenge

- Interacting and isolating the application process
  - Leveraging network namespace (i.e., a form of network virtualization)
  - Creating networking stack, each of which interacts with user-preferred applications

- Exploiting multiple wireless networks
  - Using SDN-based approach for flexible forwarding
  - An SDN switch associates several wireless interfaces

- An extra wireless interface
  - Forming a networking stack for application
  - Providing an interface for remote control component (e.g., SDN controllers)

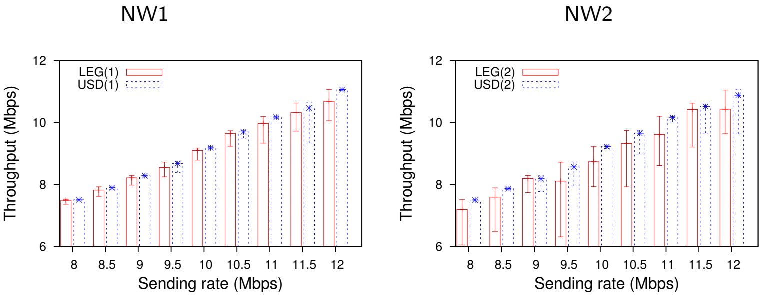
Experimental Setup



Prototype USD

- On Ubuntu with Open vSwitch 2.3.1 (i.e., SDN switch)
  - Associating several virtual Wi-Fi interfaces
- ITG-Send sends UDP traffic to ITG-Recv through the network one (NW1) and network two (NW2)
  - Comparing to the legacy Ubuntu stack (LEG)

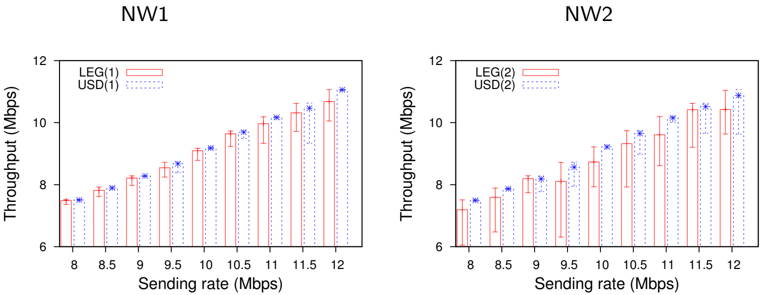
Throughput comparison



Tx

- The sending rate increases, the achievable throughput increases with both LEG and USD

Throughput comparison

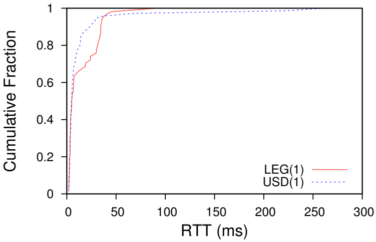


Tx

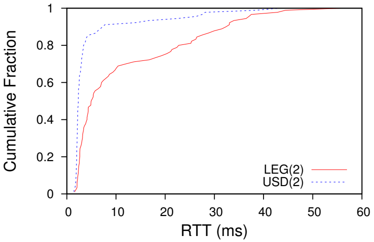
- The sending rate increases, the achievable throughput increases with both LEG and USD
- USD and LEG have comparable performance

RTT comparison

Network one



Network two

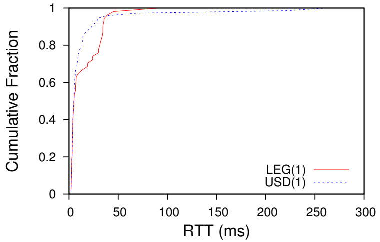


RTT

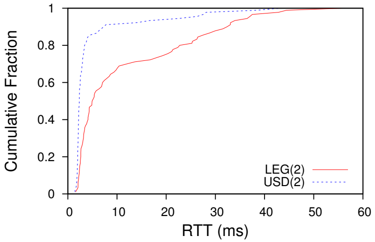
- The similar observation is seen in the RTT values

RTT comparison

Network one



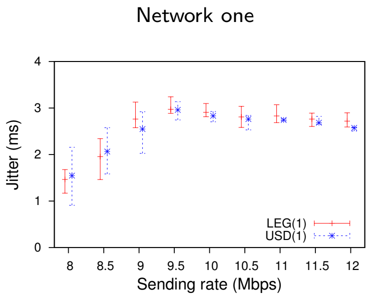
Network two

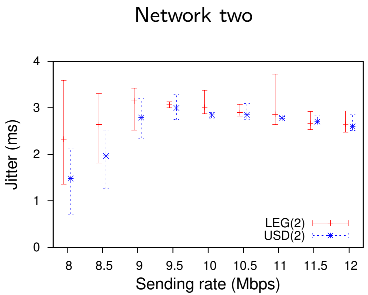


RTT

- The similar observation is seen in the RTT values
- The additional processing in USD has negligible effect on RTT

Jitter comparison





Jitter

- USD has a slightly better performance than LEG

Conclusion

- Brief Introduction of several 5G researches and developements in NICT
- MPTCP as a solution for link/path aggregations
- Extending SDN for flexible control and management in 5G wireless
- A design and implementation of user-centric platform (i.e., USD)

Thank You & Questions?

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