A Heterogeneous Software Defined Networking (SDN) Architecture for the Tactical Edge

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Modern battlefield communications networks are:

- Heterogeneous (radio, bluetooth, zigbee, wi-fi, cellular, satellite)
- DenseNets: High dense heterogeneous network
- Highly mobile (walking soldier to a supersonic jet)
- Ubiquitous access (any where, any time)
- Ultra-Low Delay and High Throughput
Challenges

Challenges of a modern battlefield communications network:

- Heterogeneous issues (interworking, interference etc.)
- Unable to support DenseNets
- Ubiquitous connectivity and access issues
- High bandwidth and Quality of Service (QoS) demands
- High latency, loss, and signaling overheads
- Mobility management and seamless handover issues
- High energy consumption
Current Technology Gaps

- Cloudlets and Mobile Cloud Techniques:
  - conventional cloud mobile technologies for controlling small cell areas
  - High delay and loss of data
- MOCHA
  - High latency around 3 seconds
  - Slow handover
- Hard Interference and Mobility management
- Decouple data and control planes is missing
- Cannot fully support heterogeneous communications at tactical edge

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Proposed Solution

- We propose a **3-Tier (3T) Software Defined Networking (SDN)** architecture that is capable of:
  - Interworking heterogeneous densenets and devices
    - Bluetooth, Zigbee, Wi-Fi, Cellular, WiMAX
  - **Seamless Mobility and fast** handoffs
  - Decouples **data and control planes**
    - **Ultra-Low** latency, loss, and signaling overheads
  - Enhanced integration between
    - **Tier 1** - Land Tactical Network (LTN) – Physical tier
    - **Tier 2** - Battlefield Tactical Network (BTN) – Control tier
    - **Tier 3** - Joint Task Force Headquarters (JTFHQ) – Management tier
3T SDN Architecture
3T SDN Architecture for Modern Battlefield

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3T SDN Controller Architectures for Modern Battlefield

- **BTN Controller Functions:**
  - Controls all LTN infrastructures with GC at HQ
  - Provides information processing or orientation
  - Provide Coalition communications

- **HQ Controller Functions:**
  - Network Global View
  - Simplified network topology
  - Mobility and handover management
  - Network element discovery
  - Backhaul management

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Mobility Management in One Battlefield Area

- Soldier sends Logical Link Control (LLC)
- LC checks its MFIB
- LC asks GC about allocation of UE
- LC updates its MFIB and allocate UE
- LC sends periodic updates to GC with PBU (Femtocell ID, UE ID, IP)
- Soldier sends RR
- LC sends RA to DMM
- Uplink & Downlink Traffic
Mobility Management in Different Battlefields

- LC1 already has UE1 in its MFIB
- LC1 sends PBU (Femtocell ID, UE1 ID, UE2 ID) to GC
- GC sends PBU to LC2
- Creates tunnel between DMM1 and DMM2
- RA from DMM1 to UE1
- IP tunnel from DMM2 to UE2
- Uplink & Downlink Traffic

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Battlefield Session Management

Proposed URP algorithm

- Femtocells with small cell diameter and Macrocells with large diameter
- IP Multimedia Subsystem (IMS) not longer relevant
- User Rate-Perceived flow algorithm (URP)
  - LC checks URP for UE during the call
  - URP=0 LC waits T=0.5s and checks URP again
  - If URP still zero LC turns session off and update MFIB at GC
  - If URP increases again LC keep session on without any MFIB updates at GC
  - URP can solve Interference problems
  - Deep Packet Inspection (DPI) in OpenFlow Switches
Simulation Model for Battlefield

- Linux based **NS-3 simulator** used to create a virtual SDN controller and an Open vSwitch with OpenFlow protocol
- The **3-Tier** (Our proposal) and **2-Tier** (Li, et al., 2012) architectures were simulated and compared
- First - Session handoff between Femtocells and Cellular BSs simulated
- Second - Throughput with different numbers of femtocells and mobility speeds simulated
- 25 Soldiers per Femtocell
- Packet Size Distribution network traffic model used (Fraleig, et al., 2003)
Round Trip Time vs. Femtocells

- RTT was simulated for 3-Tiered and 2-Tiered SDN models against increasing Femtocells (25 users per Femtocell)
- As the number of femtocells are increased the 3-Tiered model shows
  - Lower network delay (RTT)
  - High 2-Tier Delay because using cell agent
  - Increased LTN and BTN scalability

*Delay of Three-Tiered and Two-Tiered SDN Architecture with Variable Number of Femtocell.*

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Throughput vs. Femtocells

- As the number of femtocells are increased the 3-Tiered model shows
  - Higher throughput
  - Increased capacity for DenseNets

*Throughput of Three-Tiered and Two-Tiered SDN Architecture with Variable Number of Femtocells and Links.*
This graph illustrates how the network throughput is affected by:
- The mobility/speed of soldiers in a femtocell
- The size of the femtocell
- The throughput is reduced with increased mobility of the soldiers
Throughput vs. Soldiers per Femtocell

- This graph illustrates how the network throughput is affected by:
  - the number of soldiers in a femtocell
  - the size of the femtocell

- Throughput:
  - is high from 0 to 25m
  - is reduced with increased size and number of soldiers per femtocell

Throughput of Femtocell with 25 Soldiers

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Seamless Handover

- URP algorithm will monitor the session to keep it on
- URP signals LC to check its MFIB to determine the location of soldiers by using femtocell index
- Seamless handover and delay reduction

*Throughput of Femtocell of soldiers with Handover and Overlapping of 20 meters*
Conclusion

- We present a Heterogeneous Software Defined Networking Architecture for the Tactical Edge for highly dense heterogeneous battlefield networks.
- The benefits of this novel approach is that it outperforms existing cloudlets and mobile cloud techniques for tactical communications.
- According to our simulation results:
  - Faster handoffs between mobile soldiers and devices on a battlefield
  - Improved tracking of soldiers and devices
  - Faster network mobility with seamless handoff
  - Reduce overhead signaling
  - Lower delay
  - Higher throughput and scalability
  - Simplified network operation