Over-The-Top (OTT) Aggregation Solutions

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February 12, 2019

Agenda

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- Introduction
- Why aggregation is important?
- Traditional Aggregation Solutions
- Over-The-Top (OTT) Aggregation Solutions
- Analysis of OTT aggregation solution benefits to MSOs
- OTT Aggregation Testing at CableLabs
- OTT Aggregation demo
- Q & A

Introduction

- Common goal of wireless operators
  - Provide enhanced network performance with improved coverage and increased capacity
  - Enhance quality of service with increased data rates and better user experience

- Aggregation combines small blocks of spectrum to increase the overall transmission bandwidth

- Aggregation technologies implemented by operators include:
  - Traditional carrier aggregation or channel bonding
  - LTE-Unlicensed (LTE-U) and License Assisted Access (LAA)
  - LTE WLAN Aggregation (LWA) and LTE WLAN Aggregation using IPSec Tunnel (LWIP)
  - Multipath Transmission Control Protocol (MPTCP)

- Each technology has unique network requirements and associated costs

- OTT aggregation introduces an economical way for operators to increase data rates using existing LTE and Wi-Fi infrastructures without the need to own or have access to LTE network

Why is aggregation important?

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- Need for aggregation:
  - Satisfies increasing user demand with regards to high data rates for HD videos, videoconferencing, interactive gaming, etc.
  - Provide connectivity to increasing number of wireless users and IoT devices

- Benefits of Aggregation:
  - Adds capacity and provide coverage benefits by increasing the overall bandwidth
  - Enhances network performance and ensures a high-quality user experience by enabling operators to provide higher uplink and downlink data rates

- Current aggregation methods employed by wireless operators include:
  - Carrier Aggregation (CA) in LTE used by MNOs
  - Channel bonding in Wi-Fi used by MSOs

- To further increase data rates, wireless operators are exploring new ways to implement aggregation

Standard Aggregation Solutions

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Aggregation using LTE only	Aggregation using both LTE and Wi-Fi

• Aggregating LTE carriers across licensed and unlicensed spectrum
  ○ LTE-U standardized by LTE-U Forum
  ○ LAA standardized by 3GPP
	• Aggregating carriers by using LTE in licensed spectrum and Wi-Fi in unlicensed spectrum
	  ○ LWA standardized by 3GPP
	  ○ LWIP standardized by 3GPP

• LTE-U and LAA uses primary LTE carrier acting as an anchor in licensed spectrum and secondary LTE carrier in unlicensed 5GHz spectrum	• LTE and Wi-Fi integration occurs at Packet Data Convergence Protocol (PDCP) layer with LWA and at the Internet Protocol (IP) layer with LWIP
• LTE-U does not use listen-before-talk (LBT) protocol in unlicensed spectrum similar to LAA	• LWA requires upgrade of Wi-Fi infrastructure while LWIP is a solution that is agnostic to the Wi-Fi infrastructure
• LTE-U and LAA require new access equipment, hardware changes on end user device	• LWA and LWIP require software upgrades on existing access equipment and on end user devices
• Does not utilize existing Wi-Fi infrastructure making deployments by traditional Wi-Fi operators difficult	• Leverages both LTE and Wi-Fi infrastructures, resolving coexistence problems with LTE-U and LAA

OTT Aggregation Solution

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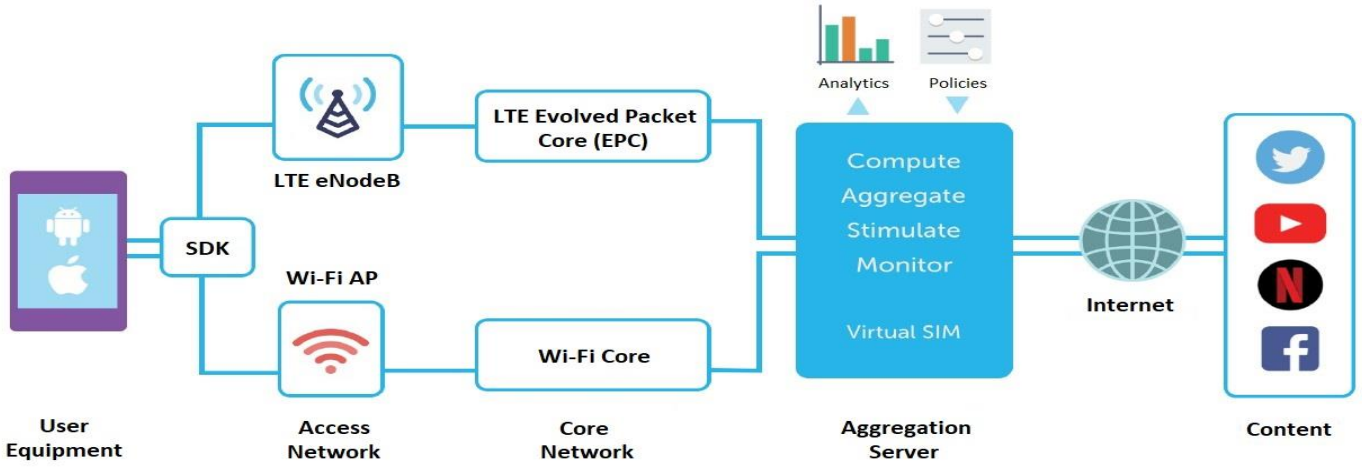
- Leverages inherent and independent LTE and Wi-Fi interfaces on mobile devices

- OTT aggregation solutions consist of two major components:
  - Aggregation Server, cloud hosted or VM-based solution
  - Client application embedded on the end user device (UE)

- Enables simultaneous use of both interfaces for data sessions by creating an IPSec tunnel between the OTT aggregation embedded app on the mobile device and the OTT aggregation server hosted in the cloud

Aggregation Server	Client Application
• Enables customized policies for optimal user experience and maximum offload to reduce costs • Measures parameters such as sub-flow throughputs, estimated bandwidths, packet loss, and latency	• Virtualizes hardware and software components and exposes a multi-path data plane in the form of a tunnel • In active state, securely establishes multi-path connections over all available network interfaces

OTT Aggregation Solution Operation



Operation in Downlink (DL)	Operation in Downlink (UL)
• Aggregation server segregates traffic on both LTE and Wi-Fi links in DL based on policies set on the aggregation server • User Equipment (UE) receives requested downlink data utilizing both LTE and Wi-Fi networks simultaneously improving the user experience and increasing the data throughput • Client application on UE combines data which was segregated by the aggregation server	• Client application on the UE will segregate the data onto both LTE and Wi-Fi links • UE sends uplink data utilizing both LTE and Wi-Fi networks simultaneously improving the user experience and increasing the data throughput • Aggregation server combines data which was segregated by the client application on UE

OTT Aggregation Solution Benefits

Key Benefits:

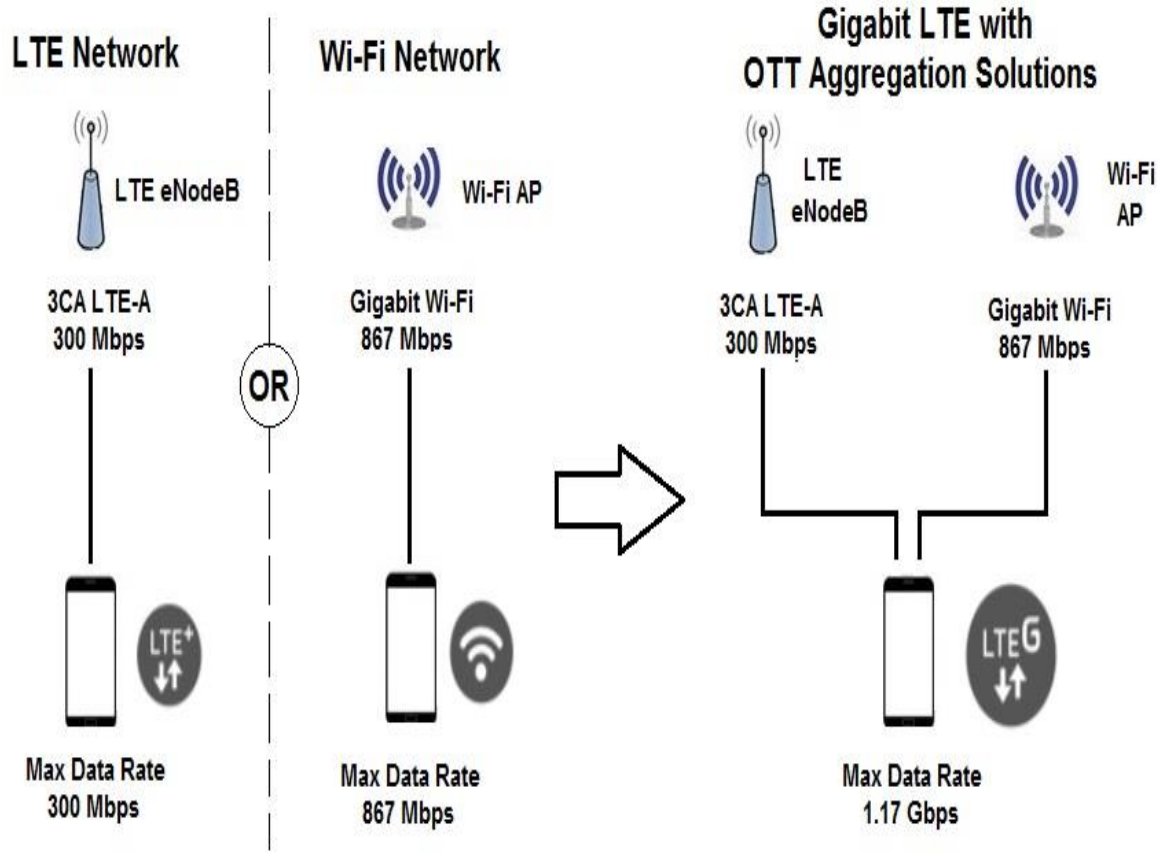
- Faster deployment
- Seamless integration
- Increased data rates
- Seamless transition with packet duplication
- Reduced operating costs

Other benefits:

- Minimal tunneling overhead
- Ability to perform content-based aggregation, location and SSID based aggregation, etc.
- Ability to switch real-time between available networks
- Ability to perform packet-based and flow-based aggregation

Unique Benefits for MSOs

- Offload traffic to less expensive connections
- Aggregate traffic on MSO owned CBRS and Wi-Fi network



Comparison of Aggregation Solutions

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	Aggregation Solutions			
Parameters	**OTT Aggregation**	**LTE-Unlicensed/Licensed Assisted Access**	**LTE WLAN Aggregartion/ LTE WLAN Aggregation with IPSec Tunnel**	**MPTCP**
Infrastructure Requirements	Can be deployed by any operators irrespective of what network infrastructure they own	Operators are required to own licensed spectrum and cellular network	Operators are required to own licensed spectrum and infrastructure or have an MVNO agreement	Can be deployed by any operators irrespective of what network infrastructure they own
Co-existence Issues	No coexistence issues	Co-existence issues with LTE and Wi-Fi operating in same unlicensed spectrum	No coexistence issues	No coexistence issues
New network elements, interfaces or protocols	Aggregation server and client agnostic to the existing LTE and Wi-Fi infrastructure	New radio access equipment	New protocols, interfaces and network elements	New network elements
End Device Support	End Device agnostic	Needs change in end device	Needs change in end device	Needs change in end device
Cost Effective	Economical	High CAPEX and OPEX	High CAPEX and OPEX	Economical

OTT Aggregation Solution Operating Modes

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- Maximum throughput mode
  - Allow users to get aggregated maximum throughput using both LTE and Wi-Fi links
  - Used when user has access to multiple networks and is using high throughput applications

- Target Throughput mode
  - Uses Wi-Fi link for all data traffic and utilizes LTE link only for the “spill over” throughput
  - Used when Wi-Fi network health is good and can handle most of the user requested throughput

- Gapless Handover mode
  - Provides a smooth transition while moving between LTE and Wi-Fi networks with packet replication
  - Used when user is transitioning between networks

- Redundancy mode
  - Provides a robust network, in case of high latency or packet loss environment, by transmitting same packets over both LTE and Wi-Fi networks
  - Useful when the network health on either or both networks is poor

OTT Aggregation Test Equipment and Setup

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Network components

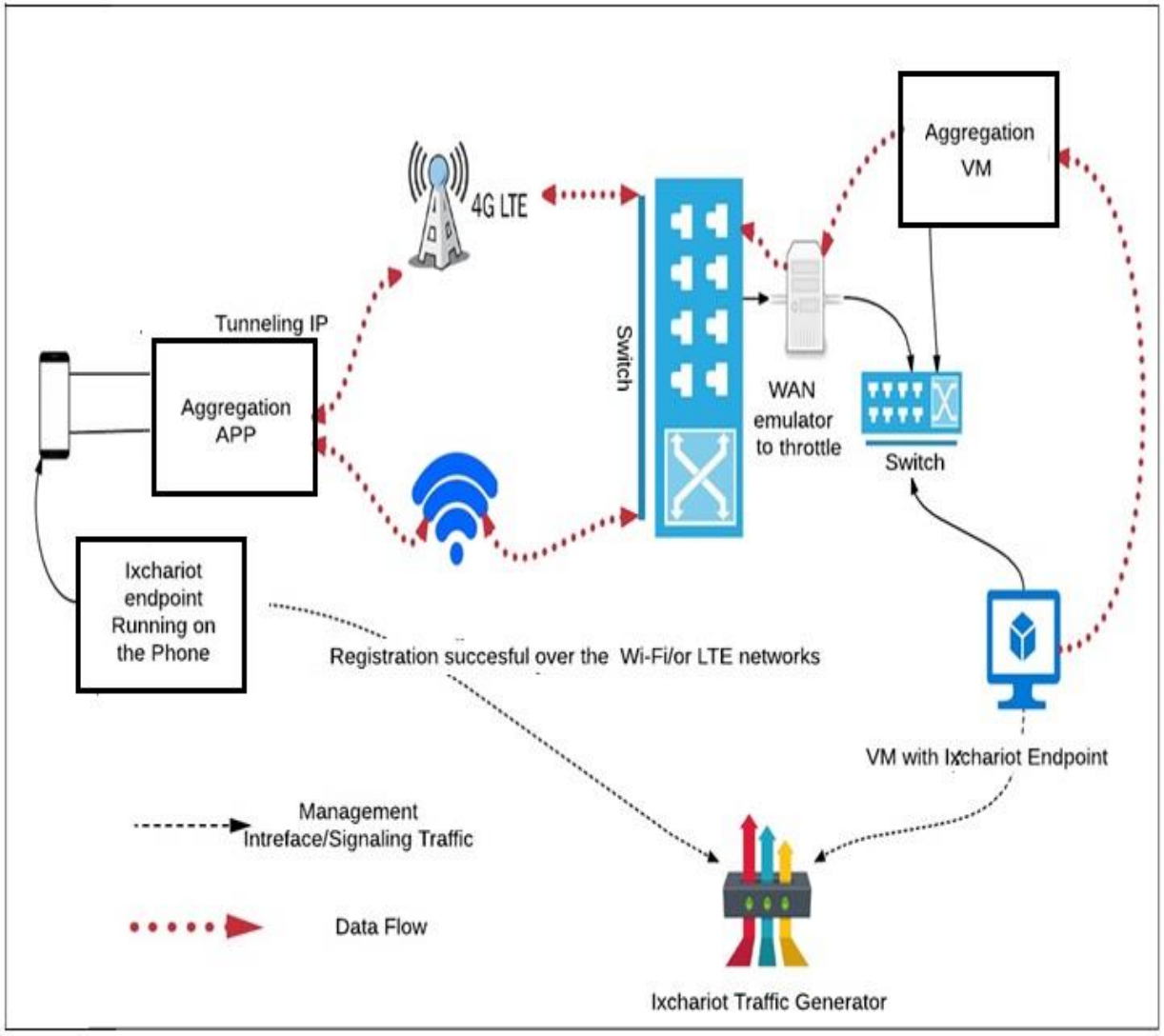
- LTE Evolved Packet Core (EPC)
- LTE eNodeB (ENB)
- Wi-Fi Access Point (AP)
- End User Device

OTT Aggregation Solution components

- Aggregation Server
- Client application

Test Equipment

- Network Emulator to replicate real world network issues such as latency, bandwidth control and frame drops
- Traffic Generator to simulate application traffic across multiple clients, generate TCP flows and record application layer throughput



OTT Aggregation Solution Test Cases

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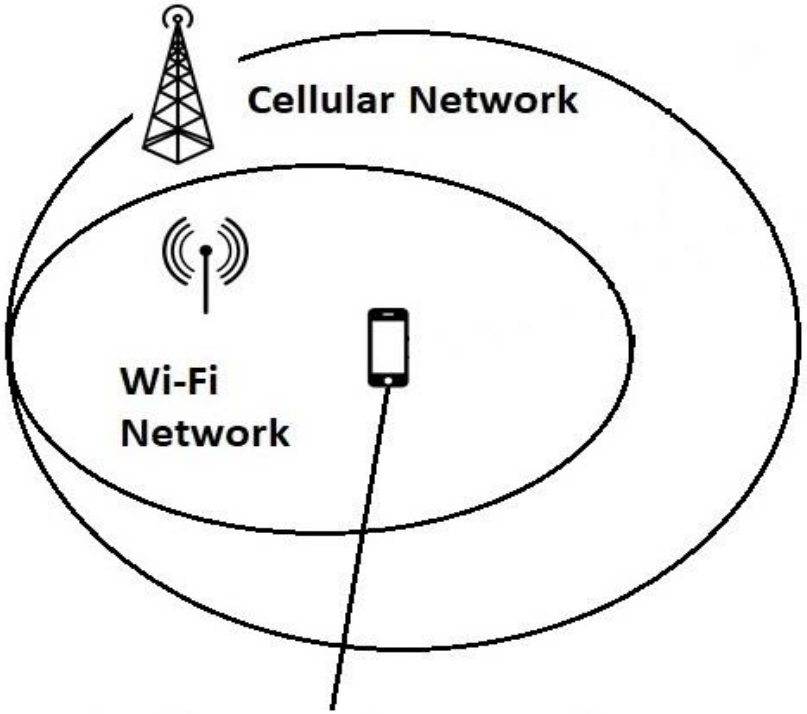
Test Case	Operating Mode	Description	OTT Solution Expected Performance
Standalone Baseline Throughput Characterization	None	Evaluate baseline performance of standalone LTE and Wi-Fi networks with and without aggregation enabled	Minimal tunneling overhead with OTT aggregation solution
Aggregation Throughput Characterization	Maximum Throughput	Evaluate the LTE and Wi-Fi aggregation performance with aggregation enabled	Increased aggregated throughput
Maintaining quality of service (QoS)	Target Throughput	Evaluate the performance using Wi-Fi network for achieving target throughput and using LTE network for the “spill over” throughput	Efficient use of cellular network when Wi-Fi is regulated to achieve the target throughput
Mobility with LTE-Wi-Fi Aggregation	Gapless Handover	Evaluate performance when the device moves between LTE and Wi-Fi networks	Gapless Handover by duplicating traffic while transitioning between LTE and Wi-Fi networks
Adjacent Channel Interference Performance	Target Throughput/ Redundancy	Evaluate user experience when Wi-Fi networks experience degradation from adjacent channel interference	Efficient use of cellular network to achieve target throughput and duplication of traffic increasing probability of traffic delivery
Congestion with multiple client	Target Throughput/ Redundancy	Evaluate performance with multiple clients at cell edge connected to both LTE and Wi-Fi networks creating congestion conditions	Efficient use of cellular network to achieve target throughput and duplication of traffic increasing probability of traffic delivery

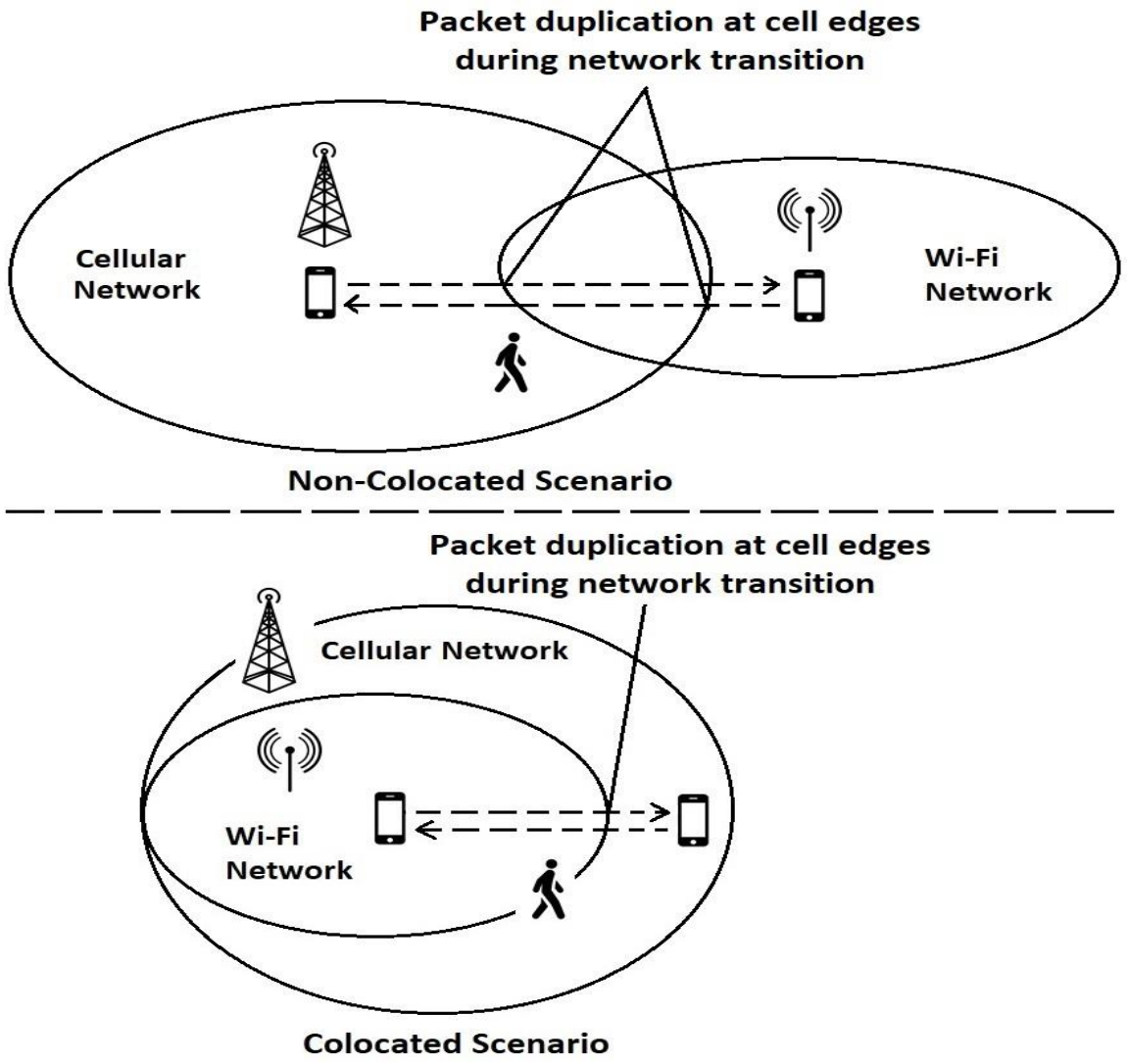
Maximum and Target Throughput Mode Testing



Device at cell center using both LTE and Wi-Fi networks simultaneously

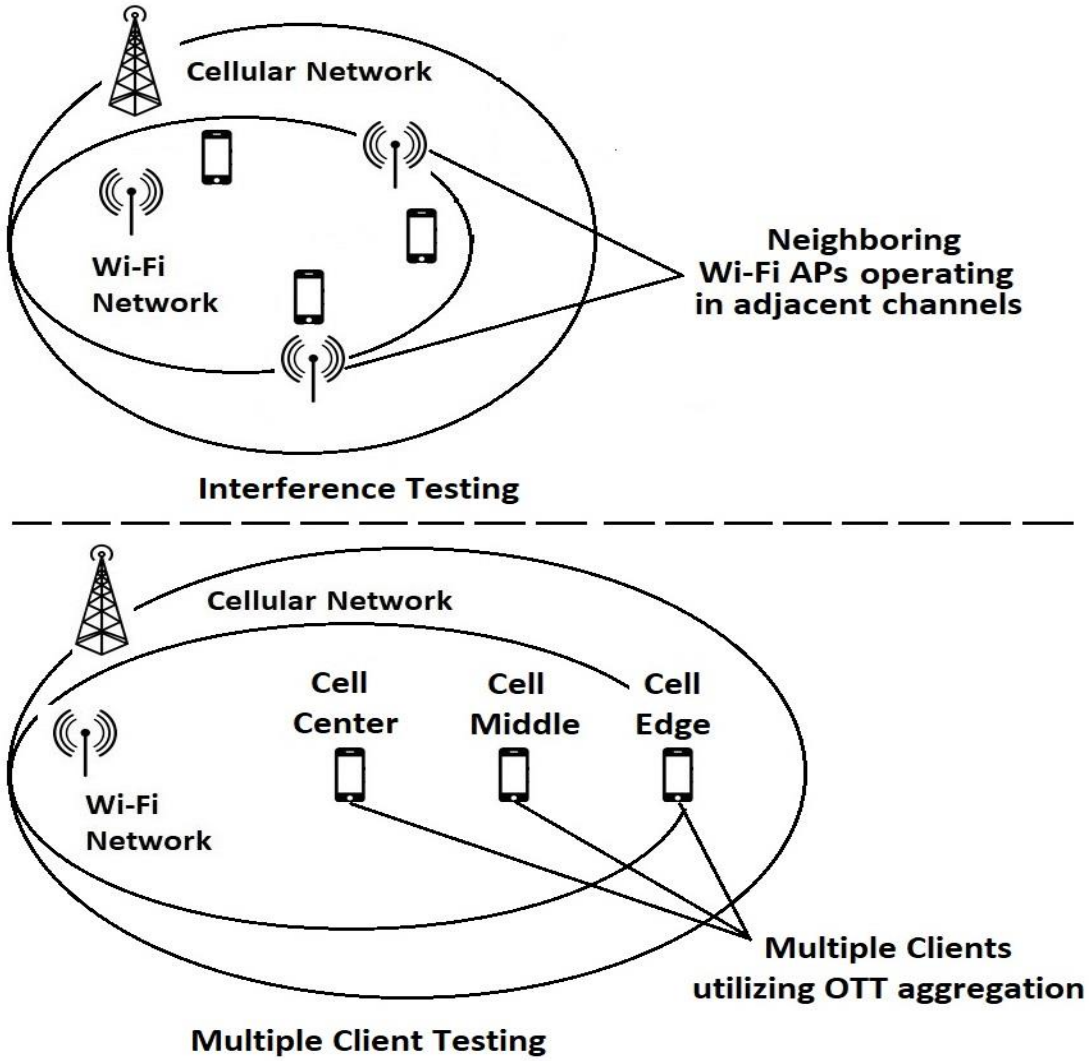
- Both LTE eNodeB and Wi-Fi AP are collocated
- Device placed at cell center of both LTE eNodeB and Wi-Fi AP
- Device has aggregation enabled operating in either maximum or target throughput mode
- In maximum throughput mode, the device utilizes both LTE and Wi-Fi interfaces to get maximum achievable throughput
- In target throughput mode, the device utilizes only Wi-Fi interface, if the target throughput is achieved and utilizes LTE interface only for the “spill over” throughput, when the target throughput is not achieved by the Wi-Fi interface
- User benefits from high data rates with maximum throughput mode and consistent throughput with target throughput mode

Gapless Handover Mobility Testing



- Gapless Handover mode tested in both collocated and non-collocated scenario with overlapping coverage areas
- In the non-collocated scenario, the device is connected to LTE network at cell center and is then moved towards the cell center of Wi-Fi network and vice versa
- In the collocated scenario, the device is connected to both LTE and Wi-Fi network at cell center and is then moved away towards the cell edge
- The device can operate in maximum throughput mode or target throughput mode when in coverage area of both LTE and Wi-Fi networks while operating in redundancy mode while transitioning between networks
- User benefits from high data rates and enhanced user experience

Interference and Congestion Testing



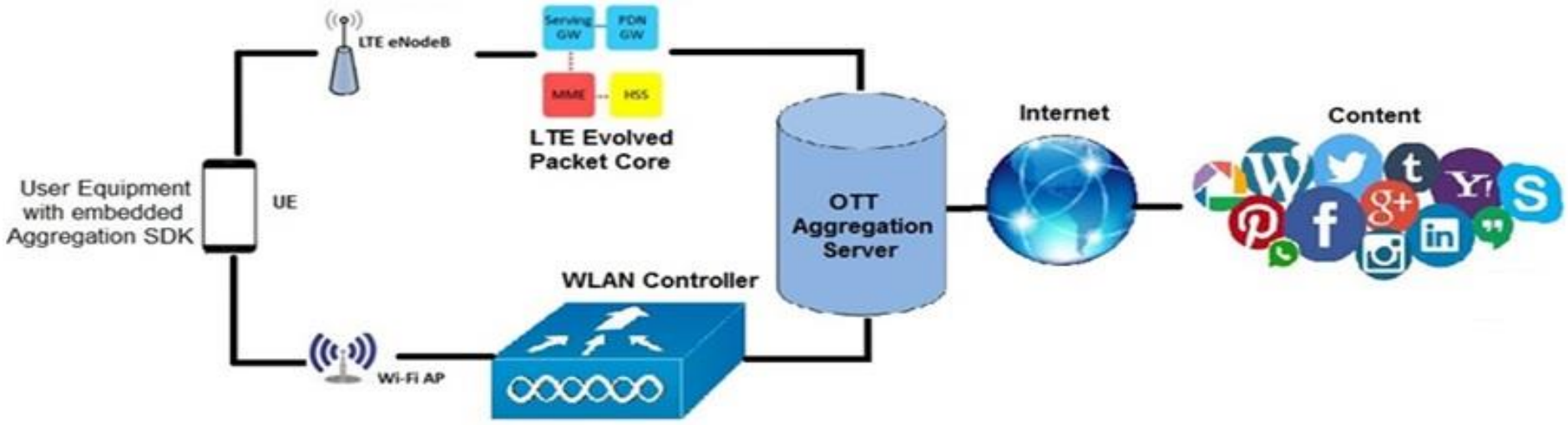
- Both LTE eNodeB and Wi-Fi AP are collocated
- In interference testing, multiple Wi-Fi APs operating in an adjacent channel are placed in close proximity to the Wi-Fi AP used for aggregation
- In multiple client testing, multiple end devices located at cell center, cell middle and cell edge are connected to the LTE eNodeB and Wi-Fi AP involved in aggregation to create congestion and loading effect
- In both scenarios, the end devices under test can utilize the target throughput and redundancy mode to enhance the user experience in challenging conditions
- User benefits with achieving target throughput with efficient use of cellular link and with improved user experience with simultaneous redundant packet transmission on both LTE and Wi-Fi interfaces

OTT Aggregation Demo

- With introduction of spectrum sharing in LTE using Citizen's Broadband Radio Service (CBRS), cable operators can increase data rates, by aggregating CBRS and Wi-Fi

- Demo showcases OTT aggregation with:
  - Citizen's Broadband Radio Service Device (CBSD) operating with bandwidth of 20MHz in Band 43 with a downlink/uplink ratio of 80/20
  - Wi-Fi AP operating in 5GHz in Channel 36 with bandwidth of 20MHz

- The CBSD is backhauled using DOCSIS with a cable modem (CM) and cable modem termination system (CMTS) between the CBSD and the LTE virtualized evolved packet core (vEPC)

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Questions?
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