ACACIA – Context-aware Edge Computing for Continuous Interactive Applications over Mobile Networks

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Continuous Interactive (CI) Mobile Apps

- Emerging Continuous Interactive (CI) mobile applications at scale
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- Example of Continuous Interactive (CI) mobile apps
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- Example of Continuous Interactive (CI) mobile apps
  - Augmented reality (AR)
Continuous Interactive (CI) Mobile Apps

• Emerging Continuous Interactive (CI) mobile applications at scale
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  • Augmented reality (AR)
  • **Face Recognition**
Continuous Interactive (CI) Mobile Apps

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  - Face Recognition
  - Virtual Reality (VR)
Continuous Interactive (CI) Mobile Apps

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• Example of Continuous Interactive (CI) mobile apps
  • Augmented reality (AR)
  • Face Recognition
  • Virtual Reality (VR)
  • **Autonomous driving**
Characteristics of CI Mobile Apps

- Highly responsive (~100 ms)
  - Overlay information (graphics, text or video) should be shown in real-time

- Intensive computation
  - Too slow to run completely on mobile devices

- Have centralized databases in the server
Enablers for CI Mobile Apps

Computation offloading to cloud
Enablers for CI Mobile Apps

Mobile network

- **3G**: 384 Kbps (2001)
- **4G**: 100 Mbps (2009)
- **5G**: 10 Gbps (2020)
Enablers for CI Mobile Apps
Enablers for CI Mobile Apps

User Context
Enablers for CI Mobile Apps
Each Components Have Evolved a Lot
Stand-alone Approach Is Not Sufficient

• The end-to-end latency of CI apps is affected by various factors
  • Network conditions (bandwidth & latency)
  • Application computation latency (object matching computation)
The end to end latency of CI apps is affected by various factors
- Network conditions (bandwidth & latency)
- Application computation latency (object matching computation)

Each approach treats others as blackbox
- Computation offloading framework
  - No consideration of mobile network complexities
- Evolving mobile network & context information
  - No well-defined protocol and interface to make synergies among them
Need a General and Holistic E2E Approach
Key Questions?

How should the three entities (application, network, and user) be jointly orchestrated and combined in a service abstraction over mobile networks to enable CI mobile applications?
ACACIA

• A service abstraction frameworks could be provided by mobile operators
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• A general and holistic end-to-end approach to enabling CI services on edge clouds over mobile network
• A service abstraction frameworks could be provided by mobile operators

• A general and holistic end-to-end approach to enabling CI services on edge clouds over mobile network

• Leverage client context information through LTE-direct
  • Orchestrate three entities
  • Optimize both network and application processing
ACACIA Usecase – Retail Mall
ACACIA Usecase – Retail Mall

AR Available in Laptop Section

AR Available in Food Section

Laptop SALESMAN

Food SALESMAN
ACACIA Usecase – Retail Mall

AR Available in Laptop Section

AR Available in Food Section

Food SALESMAN

Laptop SALESMAN

“Interest” in laptop

Retail App
ACACIA Use case – Retail Mall

AR Available in Laptop Section

Food SALESMAN

“Interest” non-Match

Laptop SALESMAN

“Interest” Match

“Interest” in Laptop

Retail App
ACACIA Usecase – Retail Mall

AR Available in Laptop Section

AR Available in Food Section

Food SALESMAN

Laptop SALESMAN

Retail AR server

Mobile Edge Clouds

"Interest" in laptop

Retail AR App
ACACIA Architecture

Diagram showing the ACACIA Architecture with components such as Sub/CI App, ACACIA device manager, CI Server, SDN/NFV EPC functions, eNodeB, and EPC functions. The diagram also indicates connections between these components and the Mobile Edge Clouds and Mobile devices.
User Context Discovery
ACACIA Mobile Edge Network

Mobile device

Sub/CI App

ACACIA device manager

CI Server

SDN/NFV EPC functions

Mobile Edge Clouds

eNodeB

EPC functions

Mobile device

Pub App

ACACIA device manager

Radio Access Network

Core Mobile Network
Context-aware Application Optimization
User Context Discovery

Mobile device
- Sub/CI App
- ACACIA device manager

Mobile Edge Clouds
- CI Server
- SDN/NFV EPC functions

Mobile device
- Pub App
- ACACIA device manager

Radio Access Network

Core Mobile Network

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ACACIA Device Manager

- Works as a proxy between CI apps and LTE modem
ACACIA Device Manager

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ACACIA Device Manager

• Manage the network connectivity on demand
ACACIA Device Manager

- Manage the network connectivity on demand
ACACIA Mobile Edge Network

Mobile device

Sub/CI App

ACACIA device manager

Mobile Edge Clouds

CI Server

SDN/NFV EPC functions

Mobile device

eNodeB

EPC functions

Pub App

ACACIA device manager

Radio Access Network

Core Mobile Network
ACACIA Mobile Edge Network

Mobile Edge Clouds

CI Server

Mobile Core Component

Local LTE GW-U

Internet

LTE GW-U

eNodeB

Facebook

Dropbox
ACACIA Mobile Edge Network
ACACIA Mobile Edge Network
ACACIA Mobile Edge Network
ACACIA Mobile Edge Network

Mobile Edge Clouds

CI Server

Local LTE GW-U

Mobile Core Component

Internet

LTE GW-U

eNodeB
Requirements of ACACIA Mobile Edge Network

• On demand connectivity
  • Reduce control overhead due to two always-on connectivity

• Fine-grained CI traffic control in LTE eNodeB and LTE GWs based on service types

• No impact on the rest of traffic

• Cost effective
  • Without deploying middlebox for selective CI traffic

• 3GPP standard compatible
  • Without modification of eNodeB, LTE interfaces and protocol
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LTE/EPC QoS bearer framework with LTE Gateways using SDN & NFV
Steps to Set up Mobile Edge Connectivity

- Request mobile edge clouds connectivity
Steps to Set up Mobile Edge Connectivity

- LTE/EPC QoS bearer framework
Steps to Set up Mobile Edge Connectivity

- LTE/EPC QoS bearer framework
Steps to Set up Mobile Edge Connectivity

- LTE Gateways using SDN & NFV

![Diagram showing Mobile Edge Connectivity with LTE Gateways, CI Server, Mobile Edge Clouds, CI APP, and eNodeB connected to LTE GW-U and Internet.]
Steps to Set up Mobile Edge Connectivity

- LTE Gateways using SDN & NFV
Steps to Set up Mobile Edge Connectivity

- LTE Gateways using SDN & NFV

Traffic classification in LTE modem based on 5 tuples or other info
Mobile Edge Network

Service Interests
Application Processing is Still Heavy

Object Matching Time (sec)

1 Object  5 Objects  10 Objects  25 Objects  50 Objects

> 1 sec
Database pruning!

- 1 Object
- 5 Objects
- 10 Objects
- 25 Objects
- 50 Objects

Object Matching Time (sec)

1440 * 1080 Image
Context-aware Application Optimization
User Location Context

Geo-tagged AR Database

Section 0

User Loc

Searching space (section 6)
User Location Context

- Use standard trilateration localization
Publishers as Landmarks

- Use standard trilateration localization
  - Publishers act as landmarks
  - Use rxPower values from every service discovery message
Context-aware Application Optimization
Context-aware Application Optimization

Mobile device

AR Front-end

ACACIA device manager

(Discovery msg, rxPower)

CI Server on Edge Cloud

AR Back-end Matcher

LTE-direct Localization Manager (Trilateration solver)

Get images for cell 6

Estimated User location (1,3)

DB

Frames

User Context Data

AR Data

Searching space (cell 6)

Cell 0

Landmarks

Landmarks

Seaching space (cell 6)
Context-aware Application Optimization

**Mobile device**
- AR Front-end
- ACACIA device manager
  - (Discovery msg, rxPower)

**CI Server on Edge Cloud**
- AR Back-end
- Matcher
- LTE-direct Localization Manager (Trilateration solver)
- Estimated User location (1,3)
- Images
- Get images for cell 6

**DB**
- Landmark name
  - (rxPower

**Searching space (cell 6)**
- Cell 0
- Landmarks

**User Context Data**
- AR Data

**Frames**
- Frames

**Diagram Notes**
- Searching space (cell 6)
- Cell 0
- Landmarks
- Searching space (cell 6)
- Cell 0
- Landmarks
Context-aware Application Optimization

- User Context Data → AR Data

Mobile device

AR Front-end

(Discovery msg, rxPower)

ACACIA device manager

CI Server on Edge Cloud

AR Back-end

Matcher

LTE-direct

Localization Manager
(Trilateration solver)

Get images for cell 6

Images

Estimated User location (1,3)

DB

Frames

Tags

(Landmark name, rxPower)

Searchig space (cell 6)

Cell 0 Landmarks

Landmarks

Searching space (cell 6)
Database pruning

+  

3G  
384 Kbps  
(2001)  

4G  
100 Mbps  
(2009)  

5G  
10 Gbps  
(2020)  

+  

Location

=  ?
Mobile Edge Network

Database pruning

Service
Interests
Location
ACACIA Implementation

• Use OpenEPC for LTE core network components (MME, PCRF, PCEF)

• ACACIA mobile edge network
  • Extend OpenEPC to support split LTE Gateways and QoS framework
  • Use Open vSwitch and Ryu SDN controller for Local LTE gateways

• ACACIA Device Manager
  • Implement it as Android Service using Messenger class in android

• AR-based Retail Application
  • Pub-Sub GUI application
  • Use OpenCV library (SURF) for object matching
  • Geo-tagged object database
  • Trilateration localization solver
ACACIA Evaluation

LTE Basestation

LTE IP.access (small cell)

OpenEPC Core Network + GW-Us + MEC server

LTE Basestation

OpenEPC Core Network

GW-Us
MEC

MEC server

One+ One

One+ One

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ACACIA Evaluation Criteria

• Microbenchmark
  • ACACIA standard compliance
  • LTE GW performance
  • LTE-direct localization accuracy
• Impact of network optimization
• Impact of application optimization
• End-to-end evaluation
ACACIA Evaluation Criteria

• Microbenchmark
  • ACACIA standard compliance
  • LTE GW performance
  • LTE-direct localization accuracy
• Impact of network optimization
• Impact of application optimization
• End-to-end evaluation
End-to-end Evaluation

Benchmark: AR application with geo-tagged AR DB (105 objects in 21 sections)
End-to-end Evaluation

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End-to-end Evaluation

Benchmark: AR application with geo-tagged AR DB
(105 objects in 21 sections)

ACACIA << MEC << CLOUD
Conclusion

• Propose ACACIA - a service abstraction framework to enable CI apps

• Give insights to design mobile edge computing and use case of LTE-direct on 5G network

• Validate ACACIA design with smartphones, LTE base station and Software-based EPC

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