Content and Computation Aware Wireless Communication in Urban IoT

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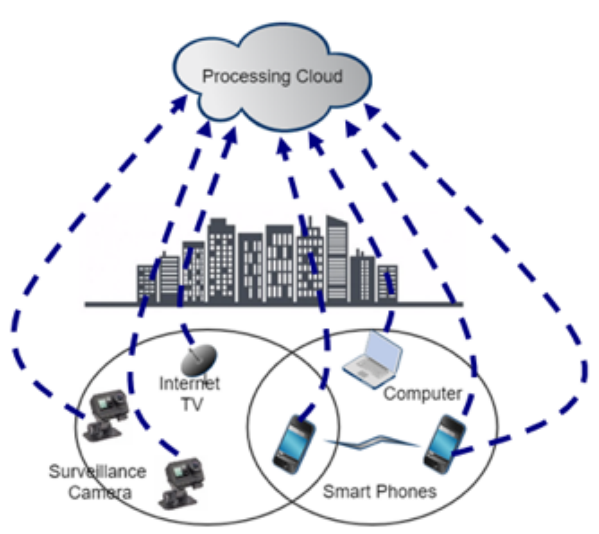
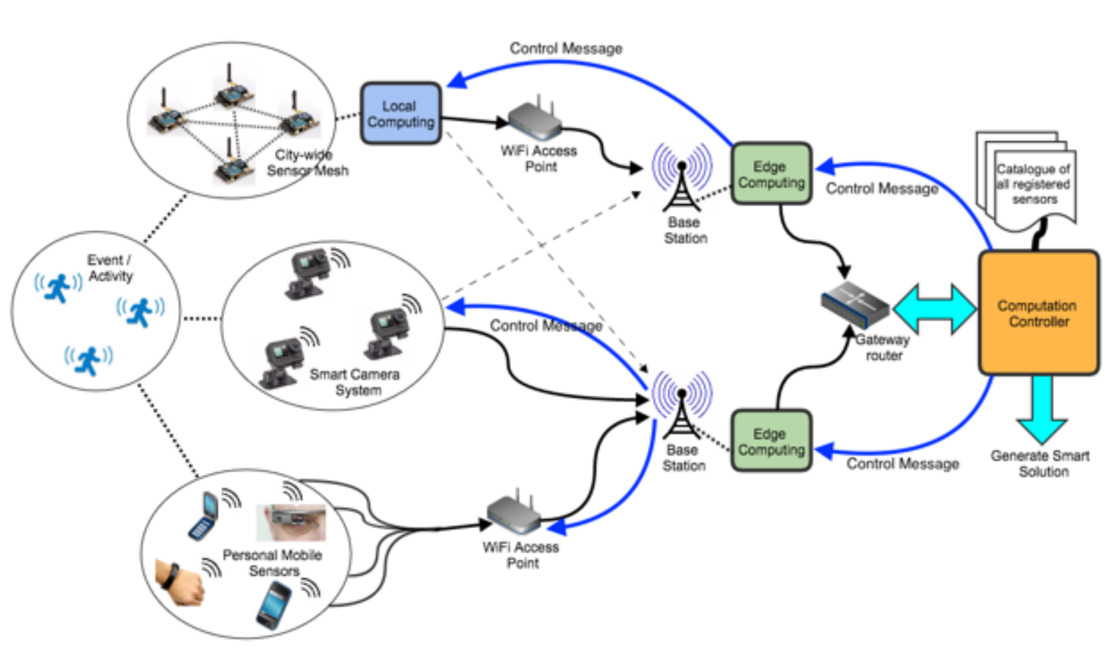
Motivation

Problems with centralized architecture of urban IoT :

- Overloads central processing cloud
- Bandwidth consumption is extremely high
- Significant increase in latency of response
- Overloads the wireless edges and routers of networks
- Redundant information flow
- Causes coexistence problem of IoT applications with traditional traffic



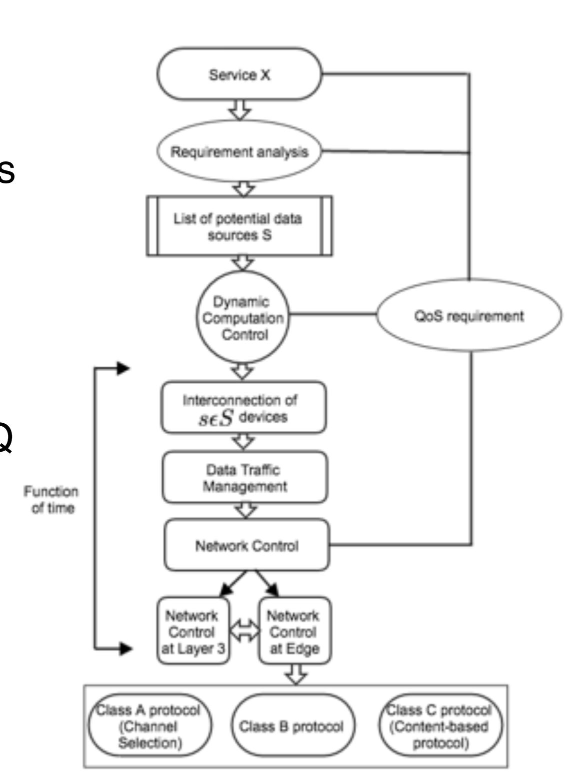
Solution: Multi-scale Architecture



Interconnect Computation & Network Control

➡Computation => Multinetwork Control => Individual network control

- Select a subset of devices to interconnect
- Interconnection is a function of time
- Delegate control to Edge with a QoS requirement Q
- Q is also a function of time

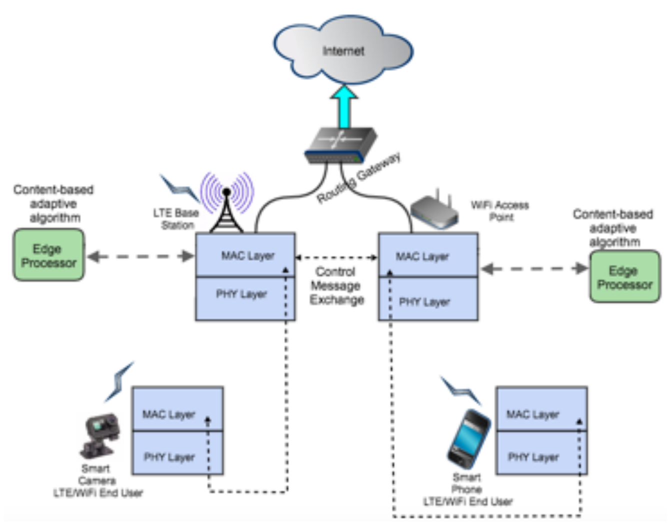


Coexistence Problem:

- Heterogeneous communication technologies share spectrum, causes interference

Wireless Coexistence and Interference

- **Example**:
  - 2.4 GHz : WiFi, Bluetooth, ZigBee
  - 5 GHz: WiFi and WiFi-Direct, WiFi and LTE unlicensed (5G)
  - LTE licensed, D2D underlay (LTE ProSe)
- **Solutions:**
  - Allocation of dedicated resources: **Inefficient**
  - Control interference at physical layer:
    - Complex to implement
    - Difficult to exchange control information across heterogeneous communications technologies
  - Cross-layer Control at layer 3 or higher:
    - Protocol delay, packets out of sequence

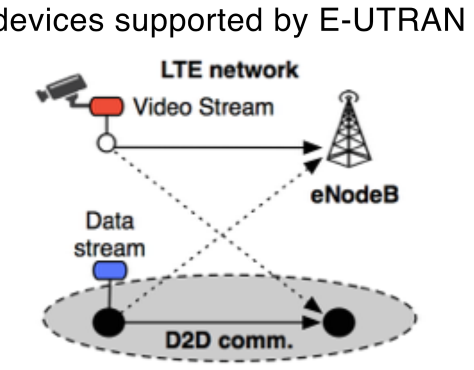


Our Approach:
Content-aware MAC protocol

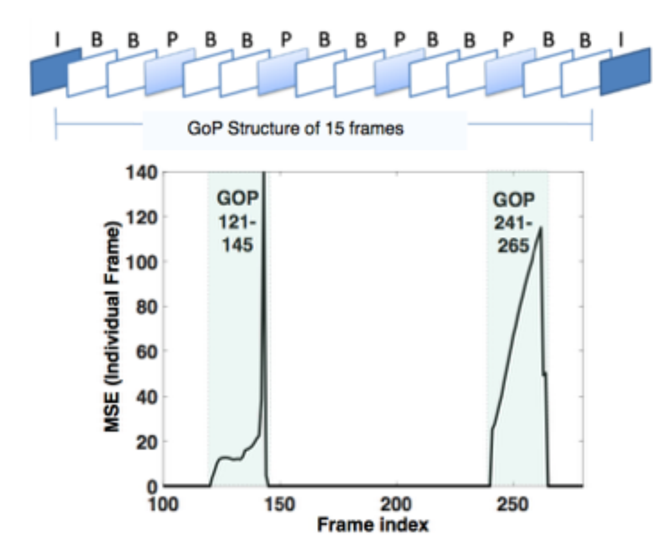
- Advantages:
  - Less protocol delay
  - Fine grained channel state information not required
  - Easy information exchange between MAC layers
  - Efficient implementation reduces control informations required

Use case scenario

- **A video surveillance application coexisting with data communications**
  Video over LTE & Data over D2D underlay of LTE in the same spectrum
- **D2D underlay in LTE spectrum:**
  - Proposed in 3GPP rel.12
  - Network Assisted: D2D underlay devices supported by E-UTRAN



- **Video Compression:**
  - **Spatial Compression:**
    - Discrete Cosine Transform
  - **Temporal Compression:**
    - GoP : Group of Pictures
    - Reference Frame / Intra-coded frame (I-frames)
    - Differentially encoded / Inter-coded frames e.g. Predicted frames (P-frames), Bi-directional predicted frames (B-frames)



★ Frame damage: effect multifold due to spacial & temporal compression

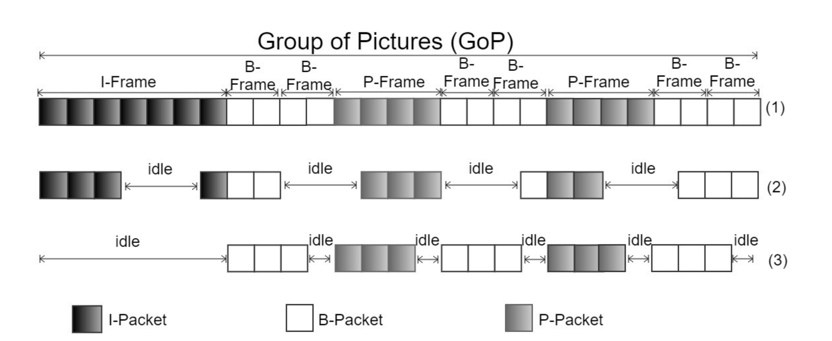
Interference Control Strategy

Optimization Problem: Maximizing D2D throughput under constraints on video quality

$$\mu^* = \arg\max_{\mu} T_{D2D}(\mu) \quad \text{s.t.} \quad D_{LTE}(\mu) \geq \delta$$

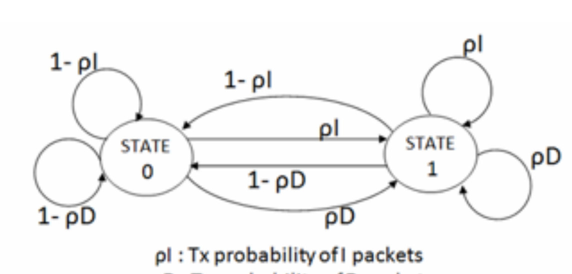
➡ Heuristics for optimal policy:

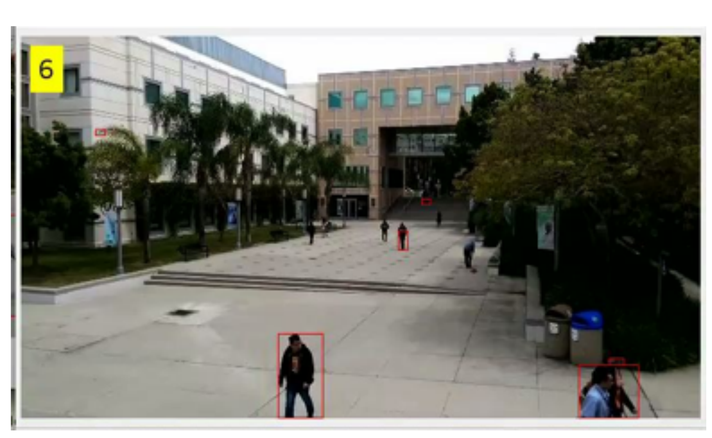
- **FDTP (Frame Dependent Transmission Probability):**
  - D2D Tx probability which is a function of transmitted frame
  - Tx Power and Channel access schemes are function of vid
  - Only statistical knowledge of the channel needed



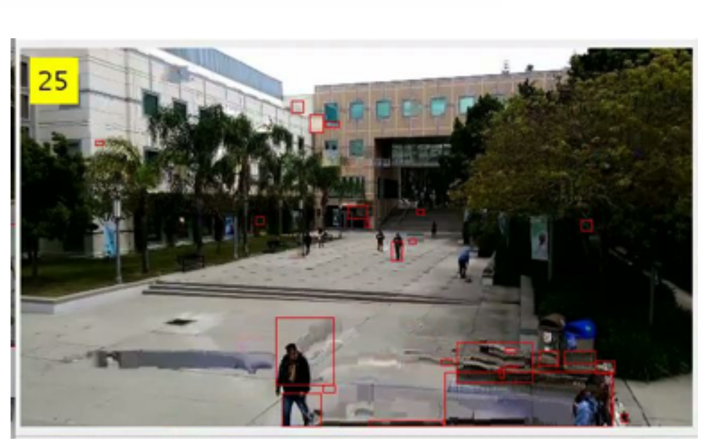
Interference Control Strategies: (1) Video packet flow (2) Fixed D2D Tx probability (3) FDTP

- **Baseline strategy: Fixed Probability (FP):**
  - D2D is agnostic about frame type of the video
  - Tx Probability of D2D is constant for all conditions





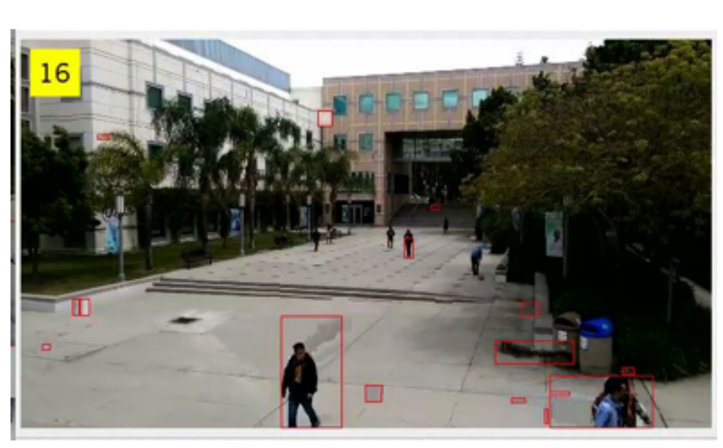
Original video frame



base case (FP)

Object tracking corresponding to interference from 10% D2D Throughput

Content-aware (FDTP)

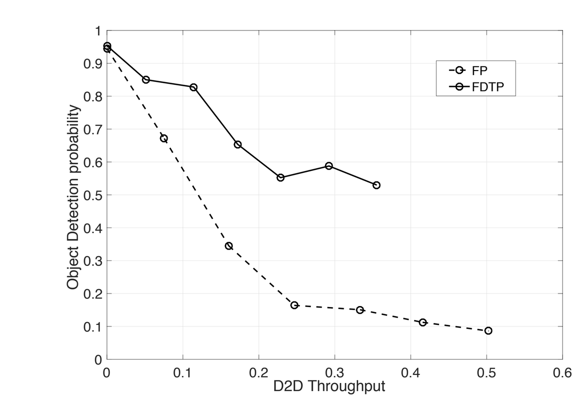


Results

Simulation LTE protocol stack on NS-3

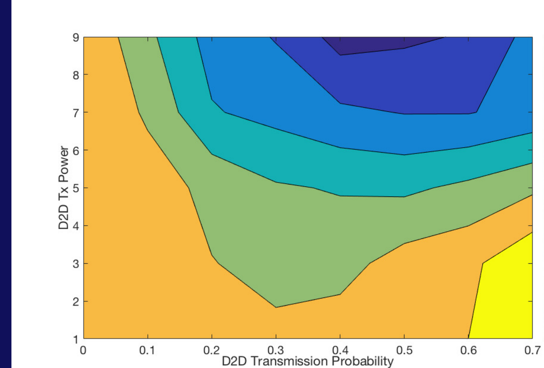
- Modified the Scheduler and MAC Tx process
- Used DATA-based interference in Uplink.

A surveillance video compressed by H.264 codec is used for the experiment. The video is converted to Transport Stream packets by using ffmpeg tool. The packets are encapsulated under UDP and send over the modified protocol stack of NS-3. We took the measurement for both FDTP and FP schemes. Each points in the graph corresponds to different transmission probability of D2D which is varied for measurement.

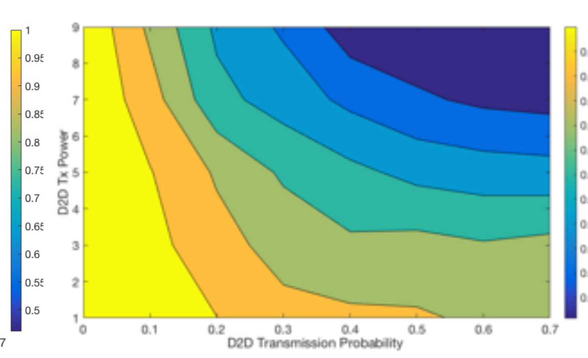


- Packet loss trace is used in MATLAB Computer Vision Toolbox to compute object detection probability
- Object Detection improves by ~ 30% by using FDTP

$$Efficiency = \frac{Object\ Detection\ Probability}{1 - D2D\ Throughput}$$



Contour Plot for Efficiency



Contour Plot for object detection

Conclusion

- Content and computation aware wireless protocols supports coexistence of heterogeneous applications
- Aims at better support for real time Urban IoT services while maintaining or improving QoS for the traditional services.
- **Constraints:**
  - The Edge computing processor should have capability to decode the content and evaluate the quality requirement
  - Heterogeneous interfering wireless technologies should be able to communicate for better spectrum utilization

References

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