# Enhancing Mobile Data Offloading with Mobility Prediction and Prefetching

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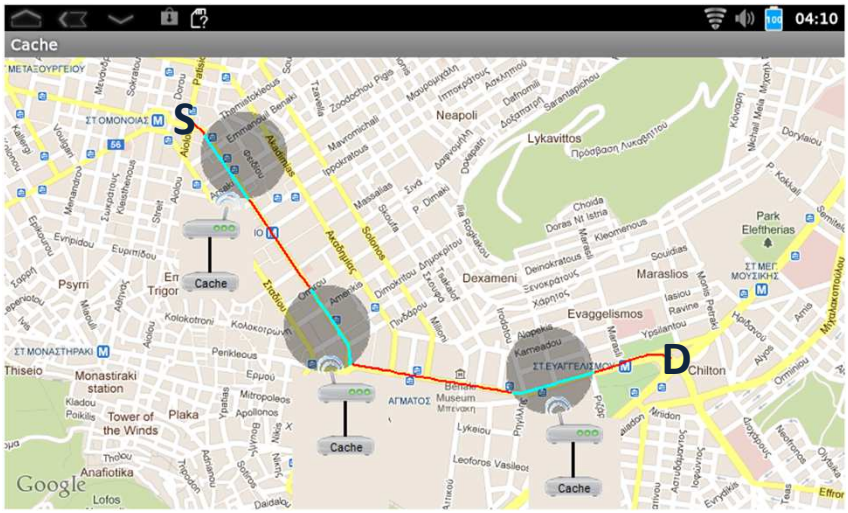
- Intelligent offloading algorithms
  - Exploit mobility & throughput information and prefetching
  - Specific procedures for delay tolerant and delay sensitive traffic
- Evaluation

# Motivation and objectives

- Investigate mobile data offloading gains from
  - Mobility prediction:
    - Human mobility patterns, vehicular route selection
  - Data prefetching:
    - Proactively cache data at WiFi hotspots
- Sensing capabilities of smartphones
  - Real-time travel data from crowd-sourcing: location & time
  - Can be used for best route selection (e.g. OptiPath app)
  - Can also collect real-time mobile & WiFi throughput information

# Mobility and throughput information



## Motivation and objectives (cont.)

- Consider both delay tolerant & delay tolerant traffic
  - Delay tolerant: increase percentage of offloaded traffic
  - Delay sensitive: reduce transfer delay
- Evaluation
  - When are there gains and how much gains
  - How gains depend on mobile/WiFi throughput, data object size, time & throughput errors

## Relation to prior work

Prior work:

- Cellular and WiFi throughput is predictable
- Throughput prediction can be used to improve media streaming quality
- Delay tolerance can improve mobile data offloading
- Prefetching is possible and can improve video streaming/reduce network load

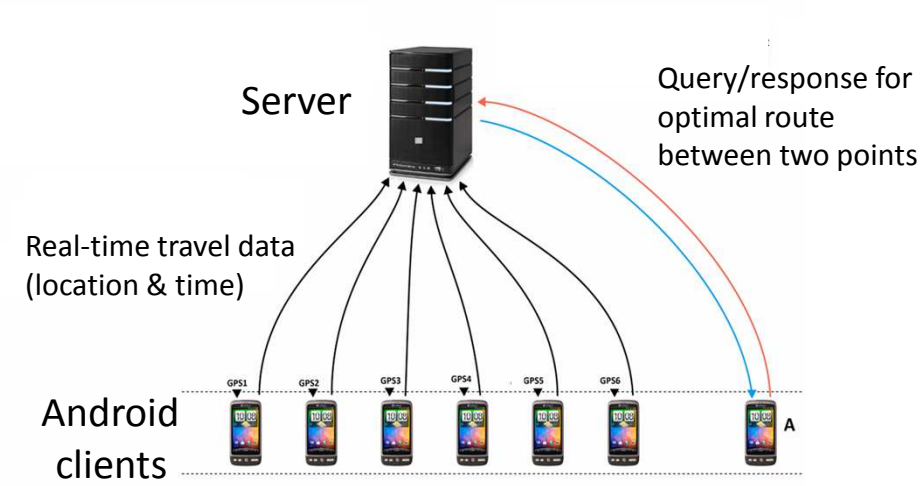
Our work:

- Develop and evaluate procedure to exploit mobility & throughput prediction and prefetching for mobile data offloading
- Specific procedures adapted to delay tolerant and delay sensitive traffic
- Robustness to location/time & throughput estimation errors

## OptiPath: Optimal Route Selection Based on Location Data Collected from Smartphones

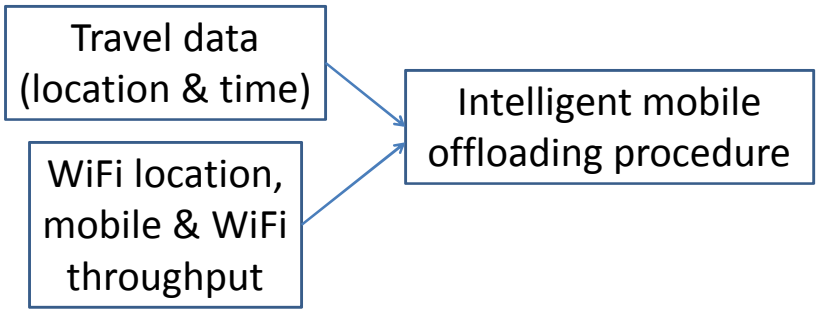
- Exploit sensing capabilities of smartphones
  - Real-time travel data: location & time
  - Collect data in central server (crowd-sourcing)
- Select route with shortest travel time
  - Obtain alternate routes from Google maps
  - Use real-time travel data to estimate travel time
- Consists of Android client & centralized server

## OptiPath Architecture

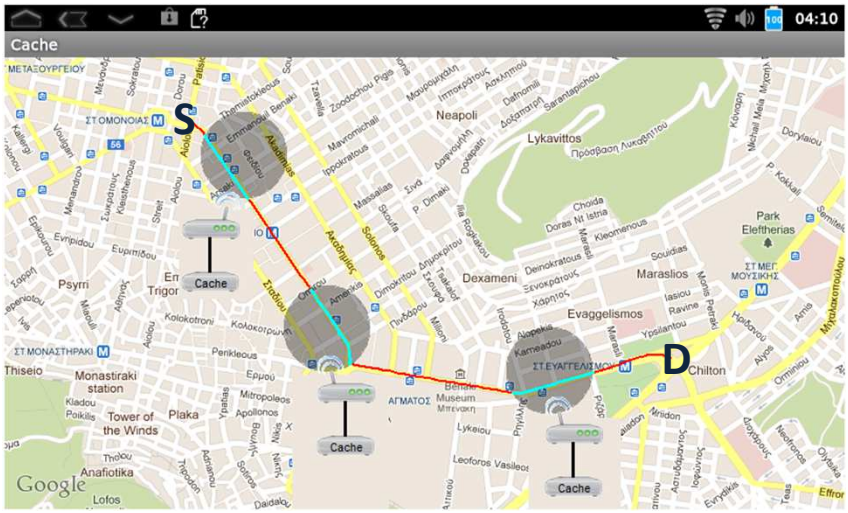


## Application to mobile data offloading

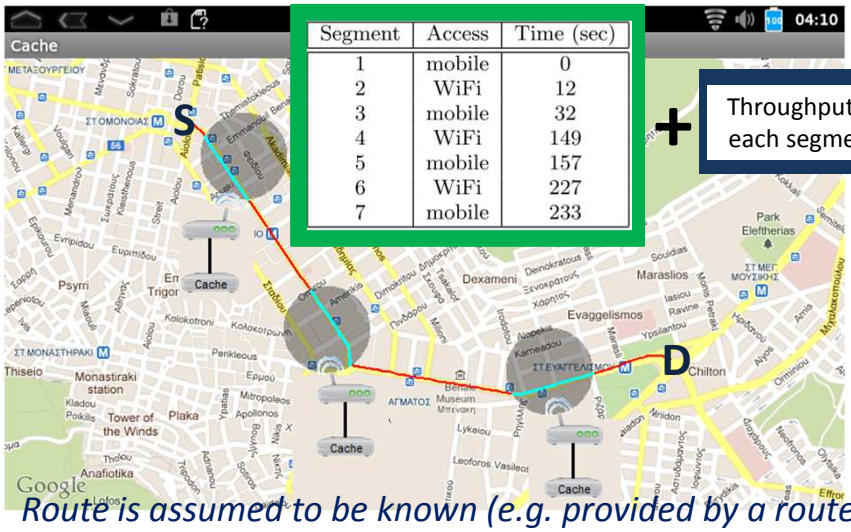
- Client-server system (crowd-sourcing) similar to systems that build database with GPS and network access & throughput information




## Mobility and throughput information



# Mobility and throughput information




| Segment | Access | Time (sec) |
|---|---|---|
| 1 | mobile | 0 |
| 2 | WiFi | 12 |
| 3 | mobile | 32 |
| 4 | WiFi | 149 |
| 5 | mobile | 157 |
| 6 | WiFi | 227 |
| 7 | mobile | 233 |

+ Throughput in each segment

*Route is assumed to be known (e.g. provided by a route selection app)*

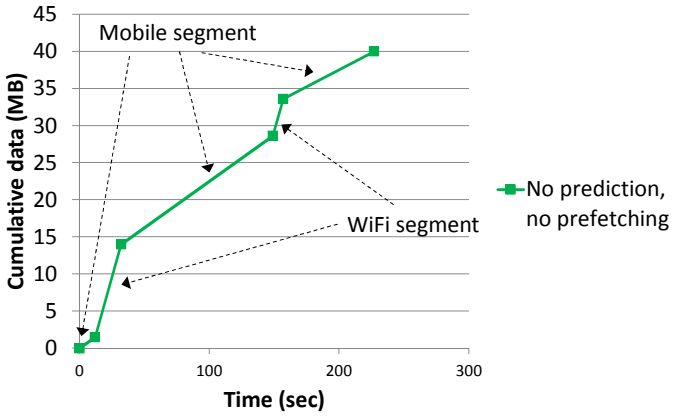
# Intelligent mobile offloading

- Offloading mobile data to WiFi already used today
- Can we achieve/how much **better performance** in terms of
  - increased **percentage of offloaded traffic** ?
  - reduced **transfer delay** ?
- Different handling of **delay tolerant** and **delay sensitive** traffic

# Intelligent mobile offloading for delay tolerant traffic

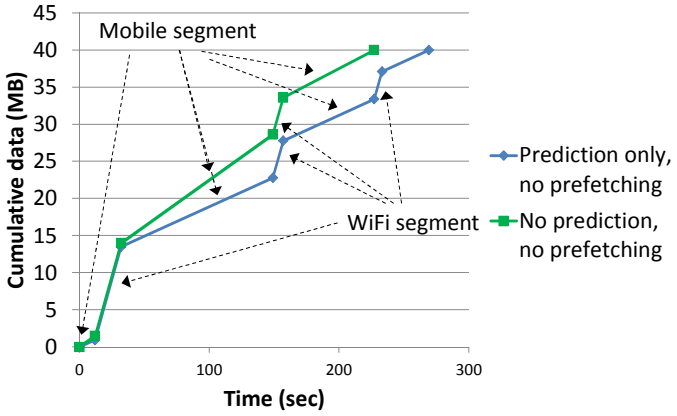
- Delay tolerant: transfer data within given delay threshold
- Objective: reduce data transferred over mobile network
- Approach:
  - Use mobility and WiFi throughput prediction to estimate **max amount of data that can be offloaded to WiFi**
  - Compute **minimum mobile throughput** required to **transfer remaining data**
  - Above defines a **schedule for data transfer**

# Behavior without prediction/prefetching




- Slope of mobile segment smaller than WiFi segment because mobile throughput lower than WiFi throughput

# Illustration of gains from mobility & throughput prediction

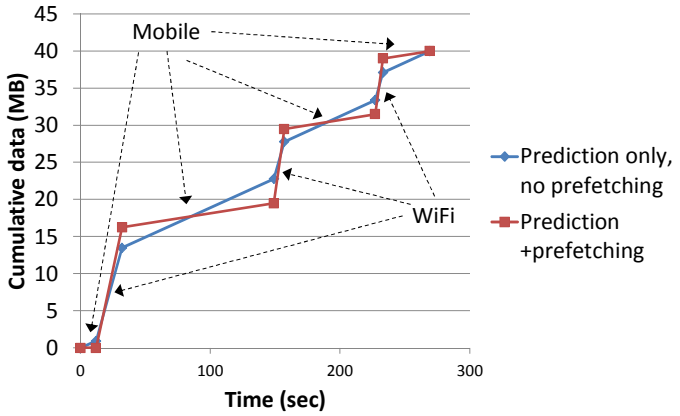



- Smaller slope of mobile segments when prediction used indicates larger amount of offloaded data

# Intelligent mobile offloading: prefetching

- Mobility and throughput prediction can be used to **prefetch** data in **WiFi hotspots** that will be **encountered along route**
- Gains if **backhaul throughput** of WiFi hotspot to Internet **smaller** than **WiFi throughput**

## Illustration of gains from prefetching

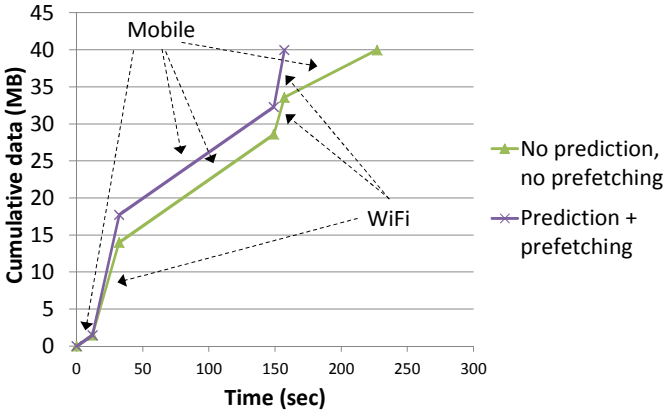



- Smaller slope of mobile segments and higher height of WiFi segments indicate larger amount of offloaded data

## Intelligent mobile offloading for delay sensitive traffic

- Objective: minimize data transfer delay
- Approach:
  - Always use **maximum mobile throughput**
  - Use mobility and throughput prediction can be used to **prefetch** data in **WiFi hotspots** that will be **encountered along route**

# Illustration of prefetching to reduce delay for delay sensitive traffic



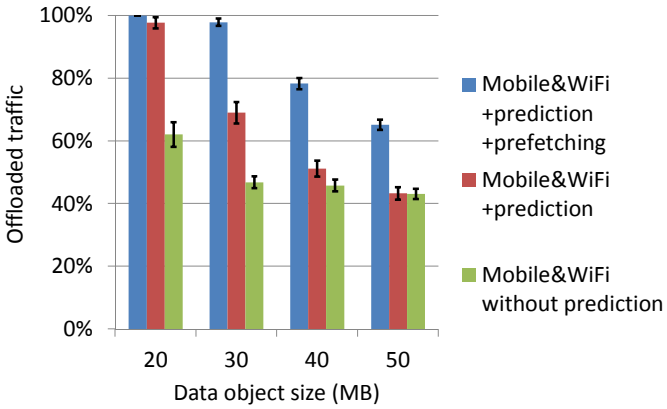

- Prefetching increases height of WiFi segments: increases amount of data transferred over WiFi, hence reduce delay

# Evaluation

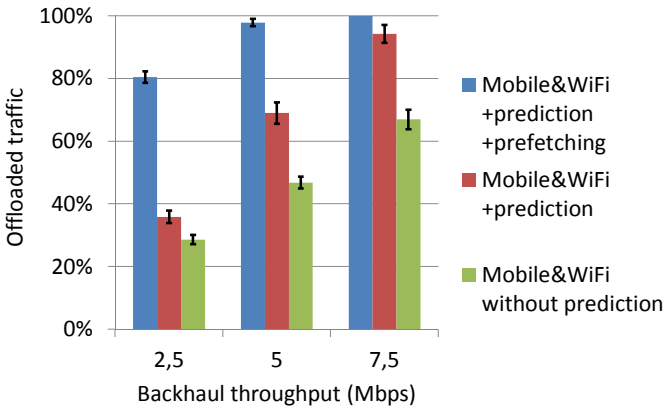
- Numerically compute data transfer for different parameter values
- Consider empirical measurements obtained using the OptiPath applications for a journey between two locations in Athens, Greece
- *When and how much do we gain from using prediction and prefetching*
- *Investigate robustness to time and throughput estimation errors*

| Parameter | Values |
|---|---|
| Data object size | 10, 20 (default for delay sensitive), 30 (default for delay tolerant), 40, 50 MB |
| Mobile throughput | 1 Mbps (average) |
| WiFi throughput | 10 Mbps (average) |
| Backhaul throughput | 2.5, 5 (default), 7.5 Mbps |
| Time error | 10% (default), 20%, 30%, 40% |
| Throughput error | 20% (default), 40%, 60% |

# Delay tolerant traffic: influence of data object size

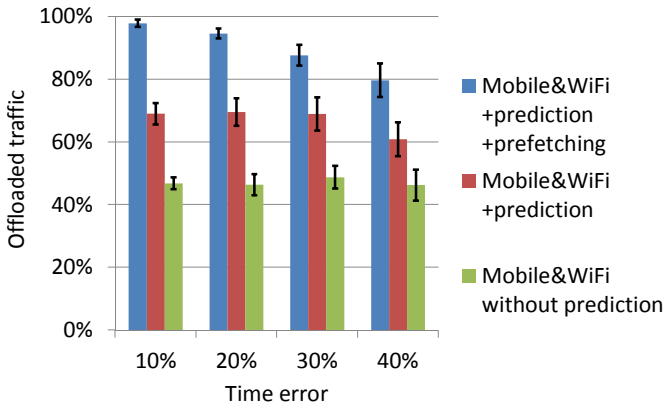



# Delay tolerant traffic: influence of backhaul throughput



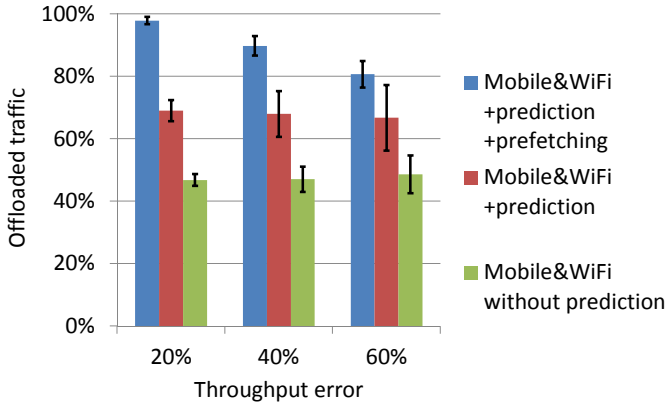
# Delay tolerant traffic: influence of time errors

- Time errors: errors in estimating when and for how long WiFi connectivity will be available

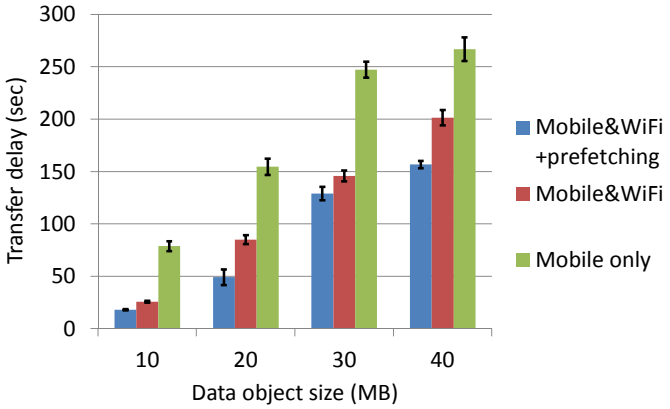



# Delay tolerant traffic: influence of throughput errors

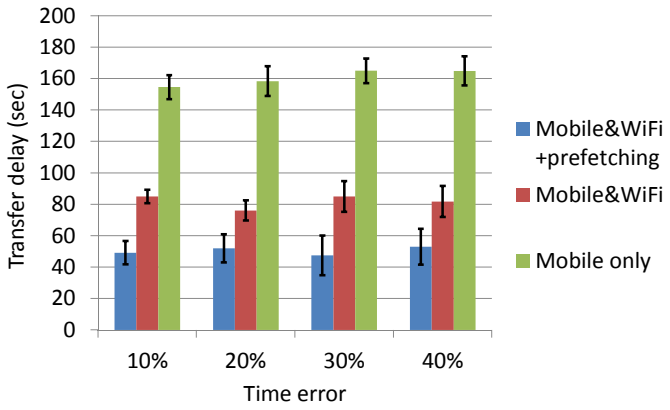
- Throughput errors: errors in estimating mobile and WiFi throughput



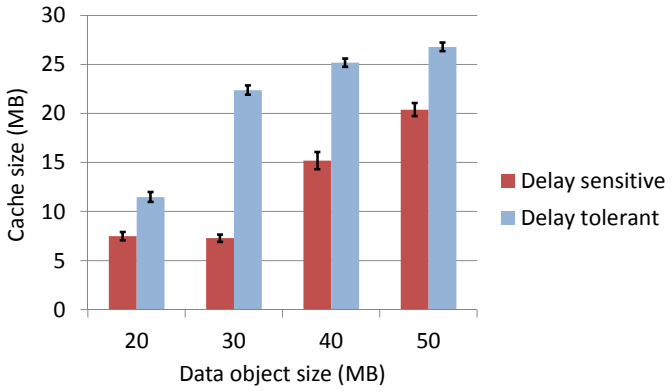
# Delay sensitive traffic: influence of data object size




# Delay sensitive traffic: influence of time errors



# Cache requirements for prefetching




# Conclusions

- Investigated procedures to exploit mobility & throughput **prediction** and **prefetching** for mobile data offloading
  - **Delay tolerant** and **delay sensitive** traffic
  - Robustness to **location/time** and **throughput errors**
- Type of mobility and throughput information determines how this can be used
  - Mobility prediction assumed route is known
  - Different approach if route not known but information on probabilities for possible next hops is known => paper in Information Centric Networking (ICN) workshop @ SIGCOMM 2012