Distribution of News Videos to Mobile Devices over Challenged Networks

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Outline

- Introduction
- System Overview
- Distribution Planning Problem
- Trace-driven Simulation
- System Prototype
- Conclusion

Background

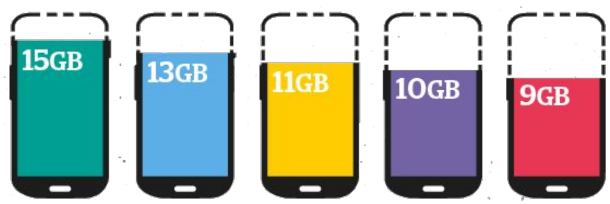
- Mobile devices are getting increasingly popular in developing countries, where mobile users rarely have the Internet access

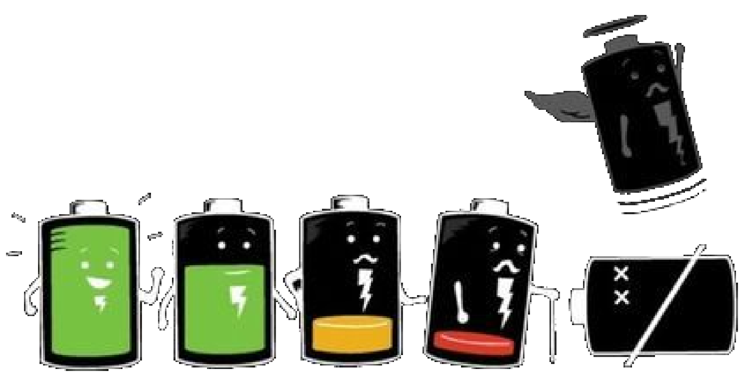
Motivations

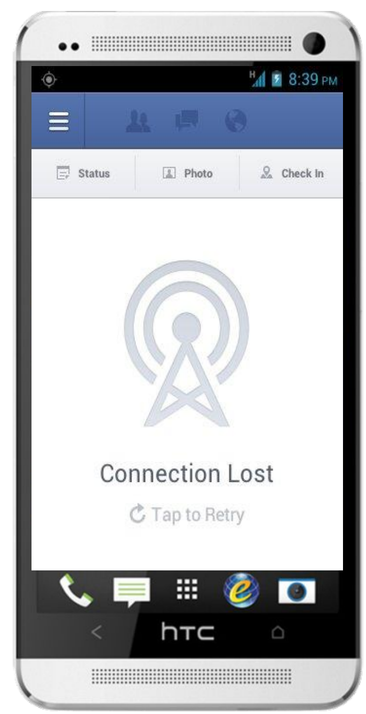
- Conquer digital divide in rural area with weak network infrastructures for online services
- Online banking, learning, health service
- Online news reports from CNN, BBC, Al Jazeera, and etc

What’s Challenged Networks

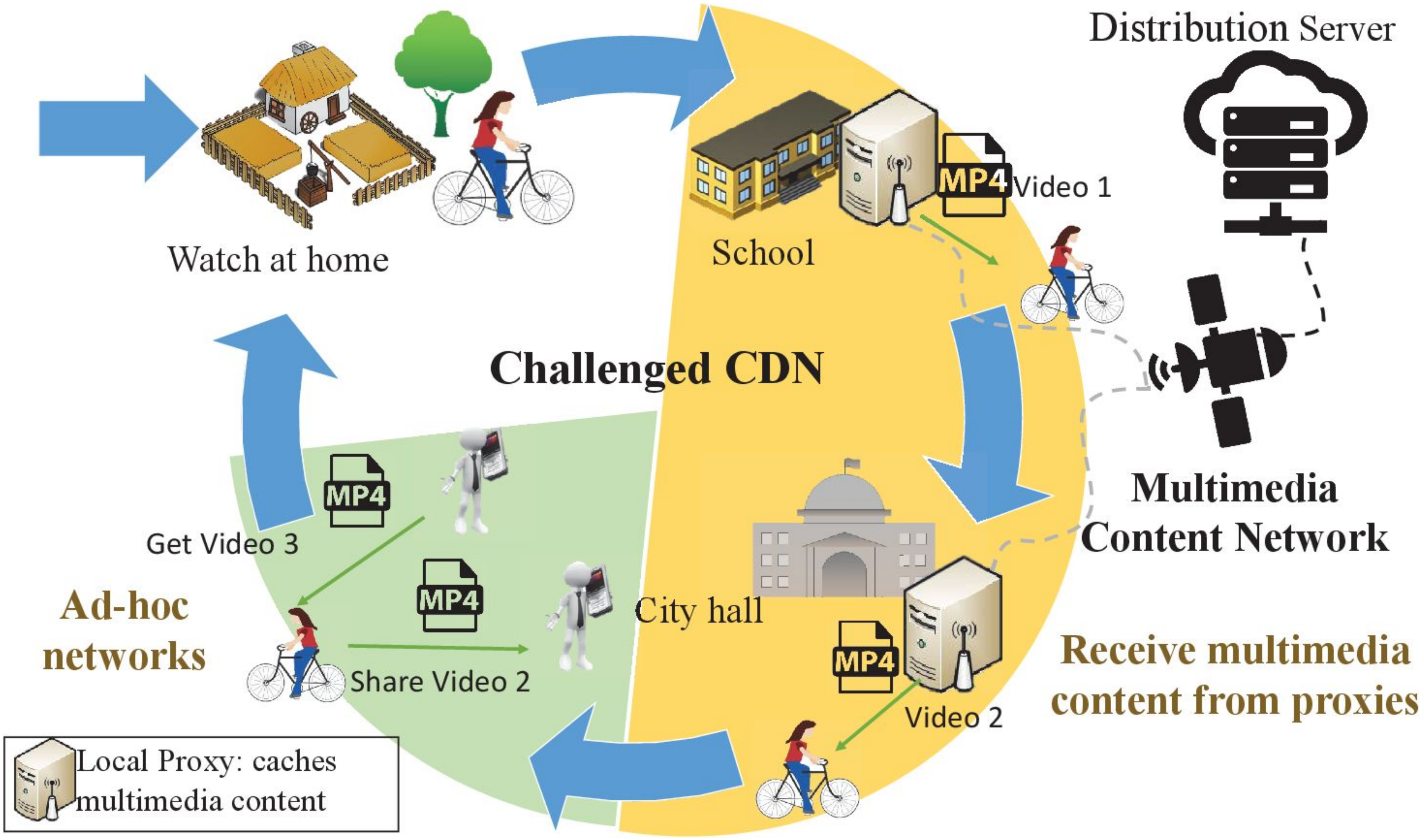
- Intermittent connectivity
- Scarce resources
- Widely varying network conditions







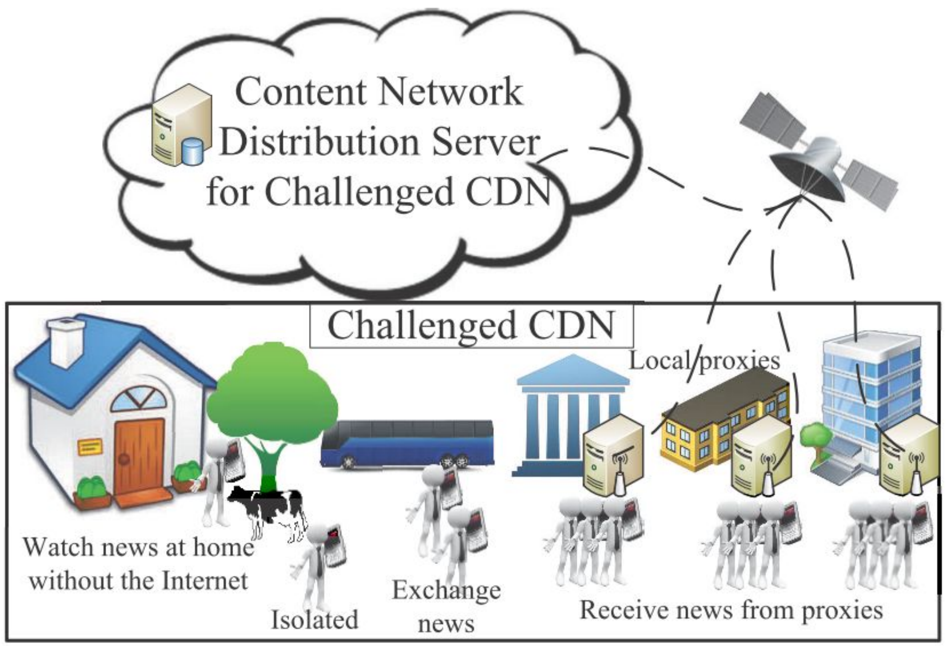
A User Story



Distribution Server
Watch at home
School
MP4
Video 1
Challenged CDN
Multimedia
Content Network
MP4
Get Video 3
MP4
City hall
MP4
Ad-hoc
networks
Share Video 2
Receive multimedia
content from proxies
Video 2
Local Proxy: caches
multimedia content

What's Challenged CDN?

- Challenged Content Delivery Networks (CCDNs) help news providers reach out to citizens living in rural areas without the Internet access



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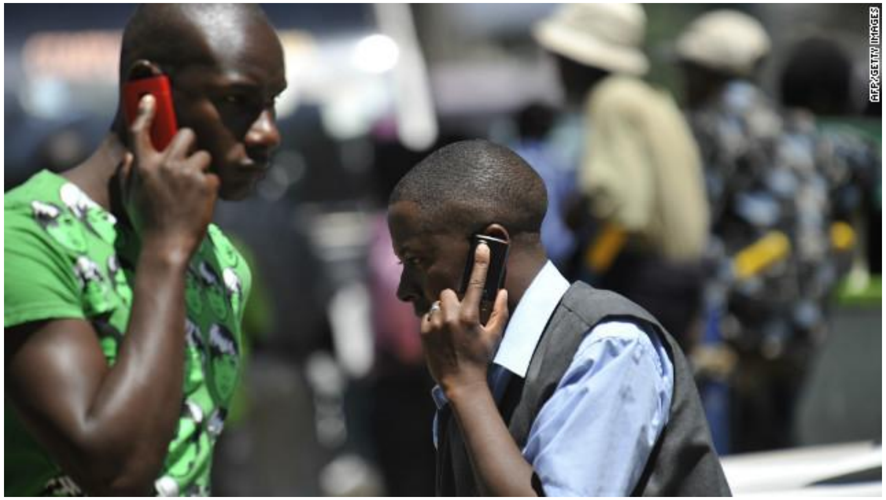
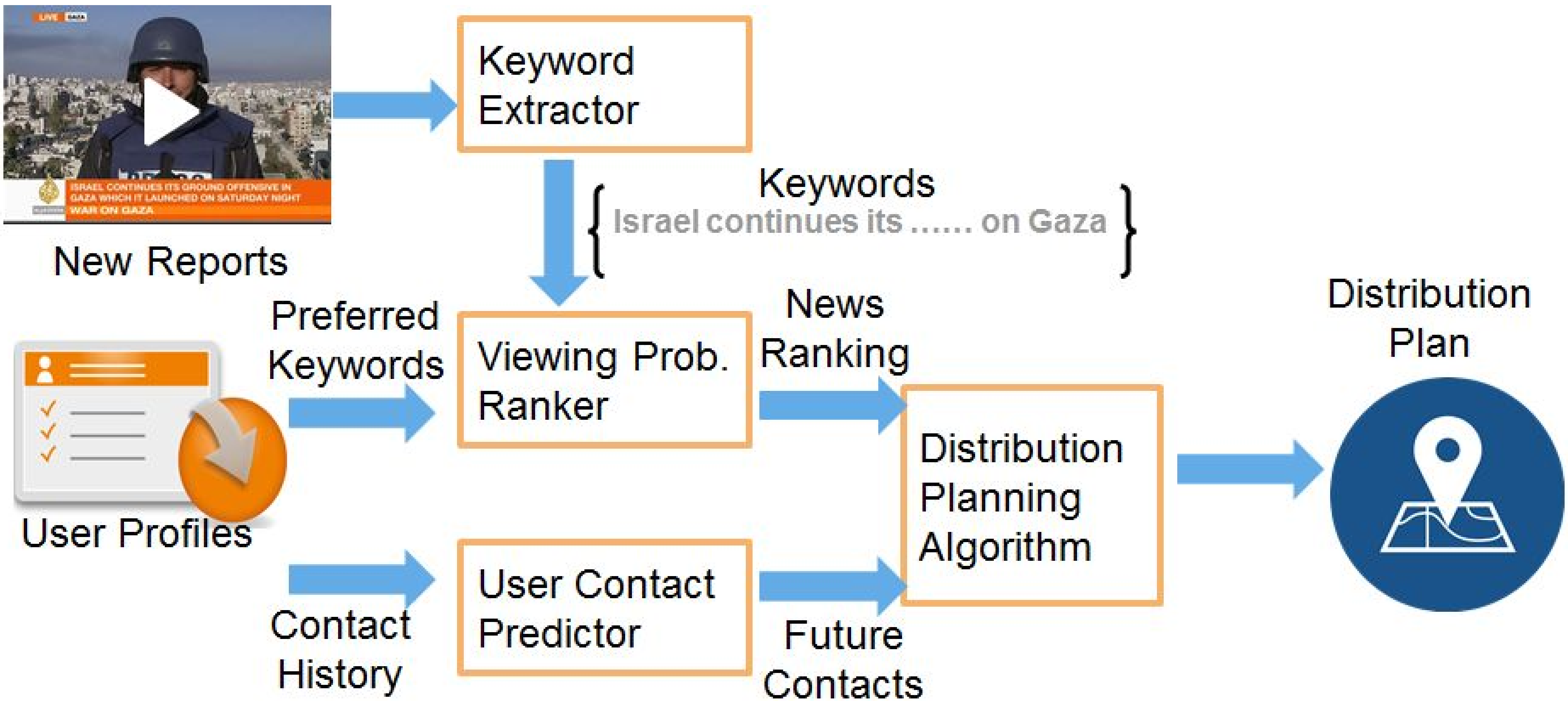
Objective

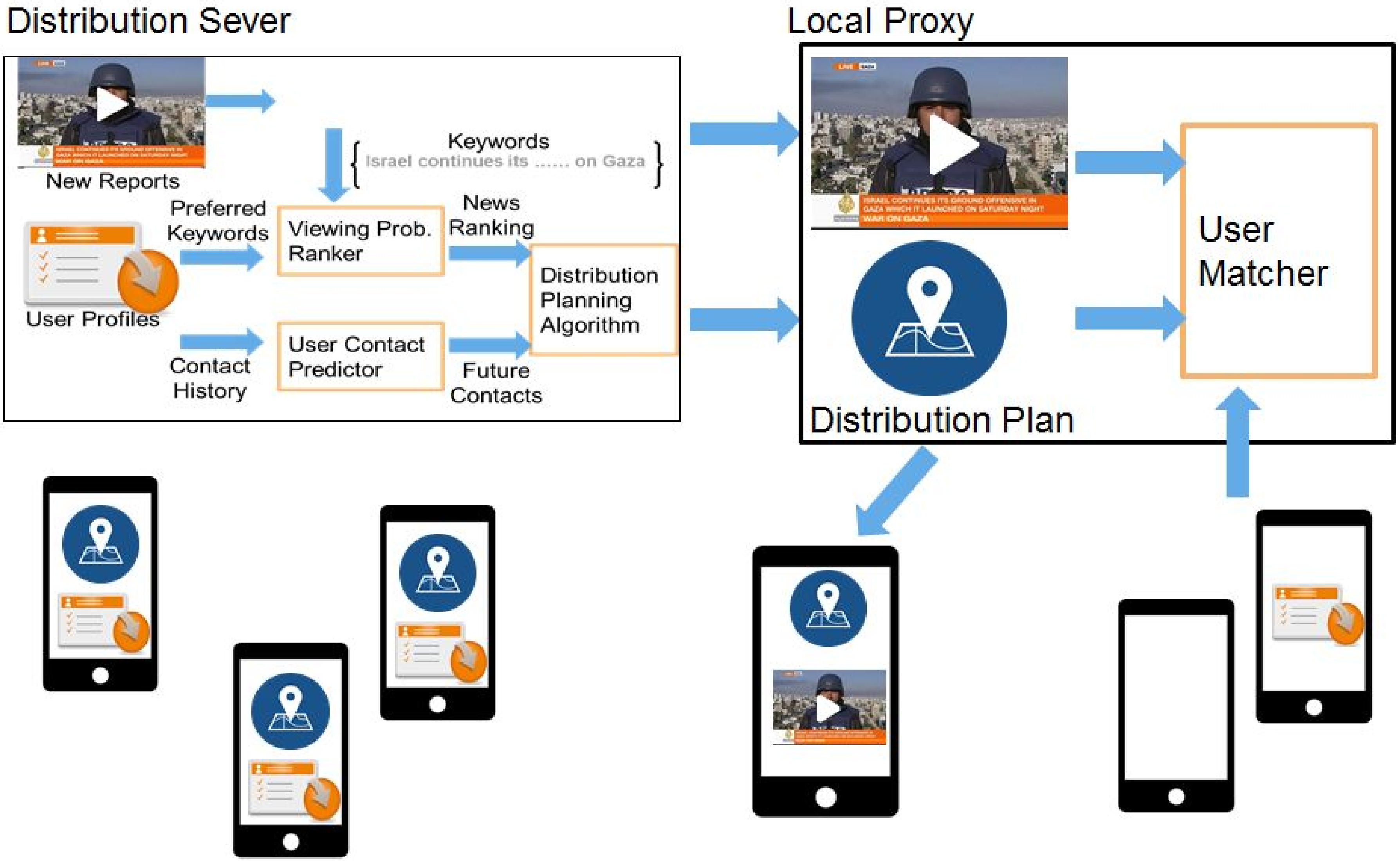
- The CCDN is aim to create a distribution plan, in order to intelligently distribute news report
  - The best time
  - The right mobile users
  - The highest possible quality



System Architecture (1/2)



System Architecture (2/2)

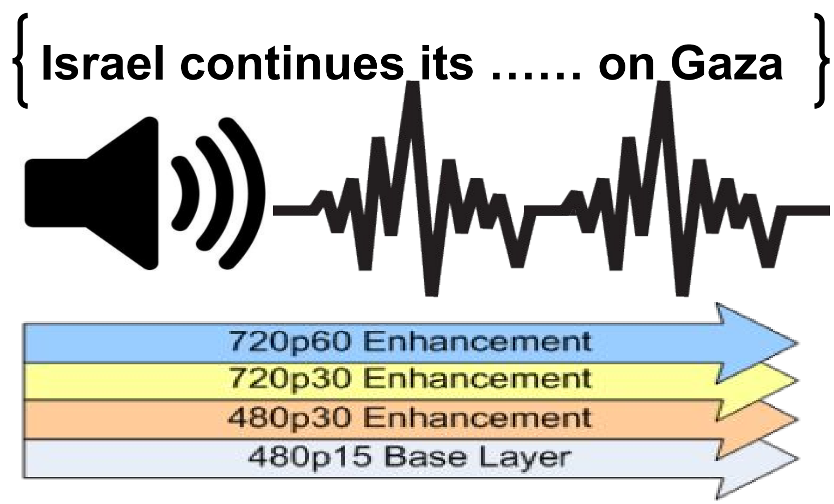


System Models

- Network Model
  - A content network that delivers news video
  - Challenged networks where mobile users rarely have Internet access
- News Model
  - Multi-layer representation of news
- Mobile Users Model
  - Users' interest and mobility are predictable
  - 85% of time a mobile users stays at his/her top 5 favorite locations

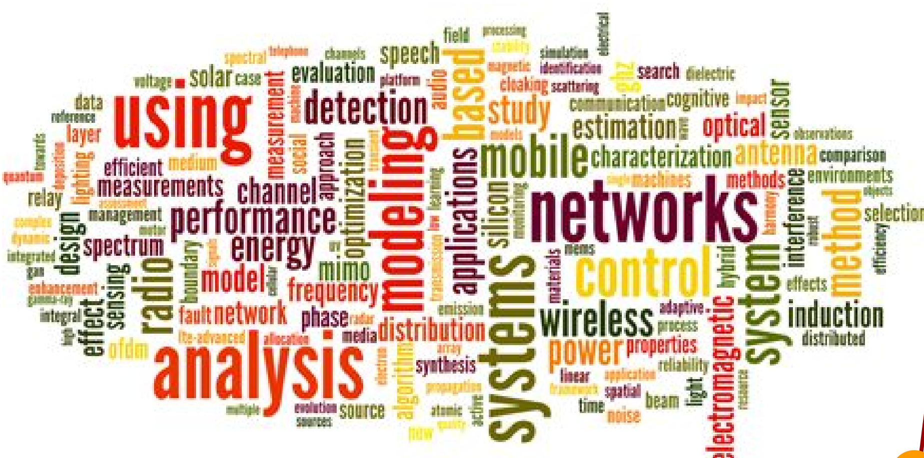
News Model

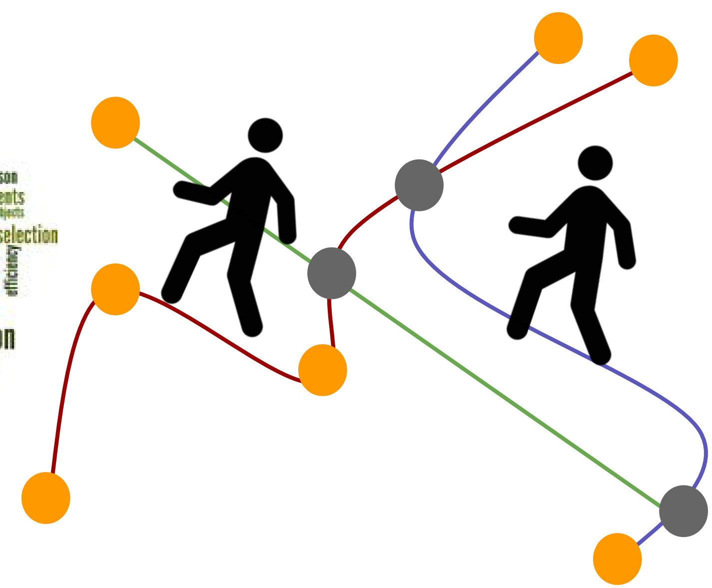
- A news report contains multiple layers: texts, audio, and layered video
- Its layers have different improvement of user experience
- To match against mobile user interests, each news reports has one or multiple topics



Mobile Users Model

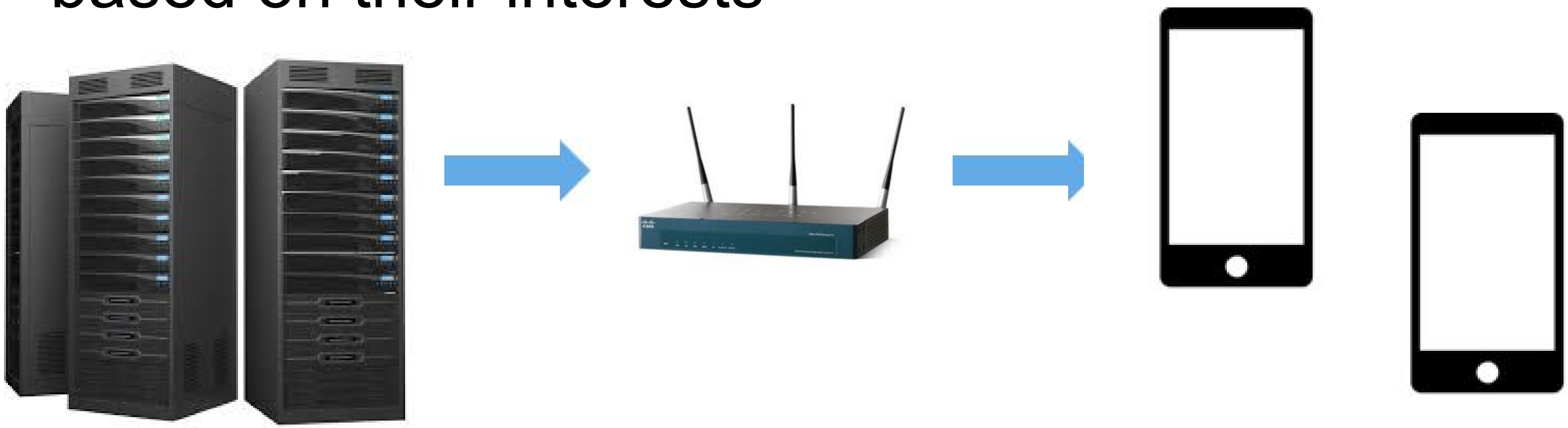
- A mobile user has
  - An interested keywords set
  - A trajectories set recorded series of timestamped locations of the user





Distribution of News Reports

- Our distribution planning algorithm computes the distribution plans for all users.
  - The distribution server pushes the distribution plan and user profile to the local proxies
  - The mobile user fetches the distribution plan when he's close to particular local proxies
  - Mobile users exchange their distribution plans based on their interests



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Problem Formulation: Objective

$$\max \sum_{u=1}^{U} \sum_{n=1}^{N} \sum_{l=1}^{L} \sum_{c=1}^{C} \underline{x_{u,n,l,c}} \; \underline{\rho_{nL+l}} \; \underline{\psi_{u,n}}$$

Decision variable for

1. which contact with which user to communicate
2. which news and layer of news to fetch

User experience improvement on the accumulated layers of news

User's viewing probability of a news report

Maximizes the expected overall user experience across all mobile users

Problem Formulation: Constraints(1/4)

$$st: \psi_{p_{u',c'},n'} \geq \bar{\psi} x_{u',n',l',c'} \quad \forall 1 \leq u' \leq U, 1 \leq n' \leq N, 1 \leq l' \leq L, 1 \leq c' \leq C$$

Minimal viewing probability

The other party of a contact

Someone's viewing probability

Mobile users never request a news report from someone who is unlikely to watch it

$$\sum_{n=1}^{N} \sum_{l=1}^{L} b_{nL+l} x_{u',n,l,c'} \leq r_{u',c'} \kappa_{u',c'} \quad \forall 1 \leq c' \leq C, 1 \leq u' \leq U$$

The size of a particular layer of news

The receiving throughput of contact c' for user u'

The receiving throughput of contact c' for user u'

Each contact duration is long enough for the planned unit transfer under the given transmission throughput

Problem Formulation: Constraints(2/4)

$$\sum_{c=1}^{C} x_{u',n',l',c} \geq \sum_{c=1}^{C} x_{u',n',l'',c} \qquad \forall 1 \leq u' \leq U, 1 \leq n' \leq N, 1 \leq l' < l'' \leq L$$

Layer dependency, i.e., higher layer is only decodable when all lower layers are received

$$\sum_{n=1}^{N} \sum_{l=1}^{L} \sum_{c=1}^{C} b_{nL+l} x_{u',n,l,c} \leq \underline{d_{u'}} \qquad \forall 1 \leq u' \leq U$$

The disk budget for user u’

Total size of planned new videos does not exceed the disk budget

Problem Formulation: Constraints(3/4)

$$\sum_{u=1}^{U}\sum_{n=1}^{N}\sum_{l=1}^{L}\sum_{c=1}^{C}\{1-\min\left[1,\max(p_{u,c},u')-\min(p_{u,c},u')\right]\}\, b_{nL+l}x_{u,n,l,c}\hat{e}_{u',c}$$

This is 1 iff $p_{u,c} = u'$, then the mobile user u plans to receive news videos from mobile user u′

receiving per-unit energy consumption

$$+\sum_{n=1}^{N}\sum_{l=1}^{L}\sum_{c=1}^{C} b_{nL+l}x_{u',n,l,c}\check{e}_{u',c} \leq q_{u'} \qquad \forall 1 \leq u' \leq U$$

transmission per-unit energy consumption

The energy budget for user u’

The total transmitting and receiving energy do not exceed the energy budget

Problem Formulation:Constraints(4/4)

$$\sum_{c=1}^{C} x_{u',n',l',c} \leq 1 \quad \forall 1 \leq u' \leq U, 1 \leq n' \leq N, l \leq l' \leq L$$

Each user does not receive the same unit multiple times

$$x_{u,n,l,c} \in \{0,1\} \; \forall u,n,l,c$$

$X_{u,n,l,c}$ is a 0-1 decision variable

Multidimensional Knapsack Problem

- Our problem is a 0-1 Integer Linear Programming problem
- Our formulation can be transformed into a 0-1 Multidimensional Knapsack Problem (MKP)

$$x_j \in \{0,1\} \; \forall j = 1, 2, \ldots J.$$

$$\max \sum_{j=1}^{J} \underline{r_j} x_j \qquad st: \sum_{j=1}^{J} \underline{w_{k,j}} x_j \leq y_k \; \forall k = 1, 2, \ldots, K$$

r_j stands for the profit of having object j

$w_{k,j}$ is the resource consumption for kth constraint

Problem Transformation

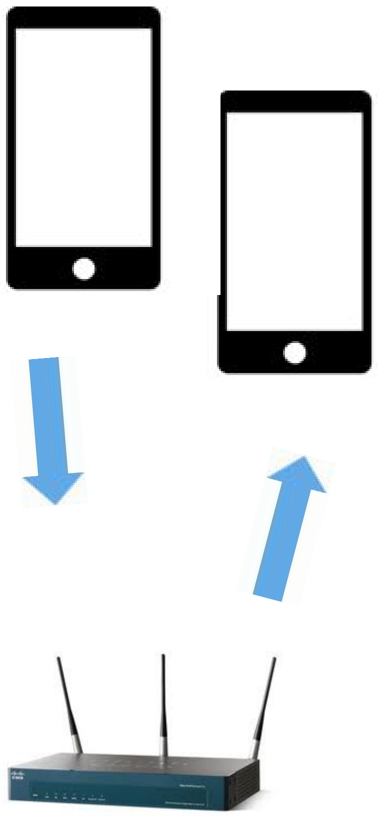
- Set $J = UNLC$, $r_j = \rho_{nL+l}\psi u, n$
- Then, $\max \sum_{j=1}^{UNLC} (\rho_{nL+l}\psi_{u,n})_j x_j$
- where $j = uNLC + nLC + lC + c \, \forall u, n, l, c$
- Next, move the decision variable to the left hand side, and leave others to the right hand side

Distribution Planning Algorithm

- MKP can be solved by several exact and heuristic algorithms proposed in the literature
- We leverage CPLEX, a commercial solver
- The workflow of our proposed Distribution Planning Algorithm
  - Transformation the news distribution problem into an MKP
  - Solving MKP using CPLEX with heuristics
  - Converting the MKP solution into a distribution plan

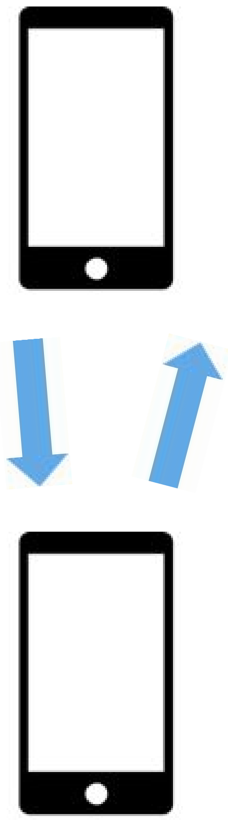
Adaptive Communication Strategies (1/2)

- A mobile device to the local proxy
  - If we do not have a plan, get one
  - Follow the plan to retrieve planned units for this contact on the local proxy
  - If finished, retrieve planned units for other contacts
  - Once the plan is completed, the local proxy runs recommendations for more news based on the user's interest



Adaptive Communication Strategies (2/2)

- A mobile device to a mobile device
  - Exchange the units that are planned to request from each other in this contact
  - If finished, exchange planned units for other contacts
  - Once the plan is completed, make the other mobile device to select particular news
- The system prefer units that have higher ratio of user experience improvement normalized to unit size



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Datasets

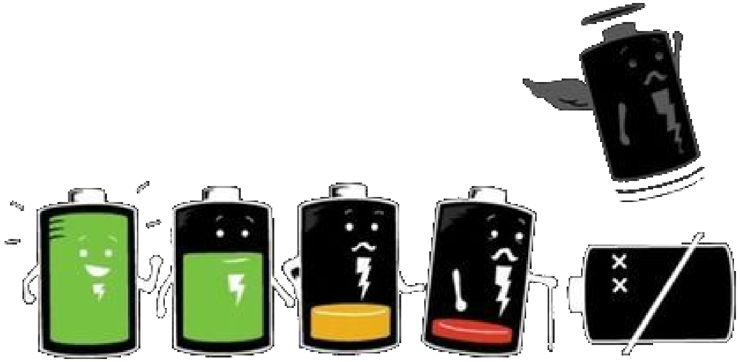
- User contacts:
  - Microsoft GeoLife dataset: GPS trajectories of about 180 mobile users over 4 years
  - SIGCOMM dataset: 76 users of bluetooth contact over 3 days
- Video reports: 27 news reports from Al Jazeera in mid-July 2014, and divide each news report into five layers
- User interests: leveraging the user queries in the Microsoft LETOR dataset

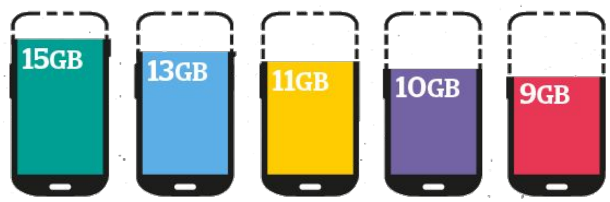
Performance Metrics - User

- User experience
  - the summation of the user experience of all the watched news reports
- Viewing ratio
  - the fraction of viewed news reports among all the downloaded ones
- Missed ratio
  - the fraction of unavailable news reports among all the user demanded

Performance Metrics - System

- Energy consumption
  - the energy consumption of mobile devices
- System efficiency
  - the ratio of user experience and energy consumption
- Used disk space
  - the amount of used disk space.





Simulation Setup

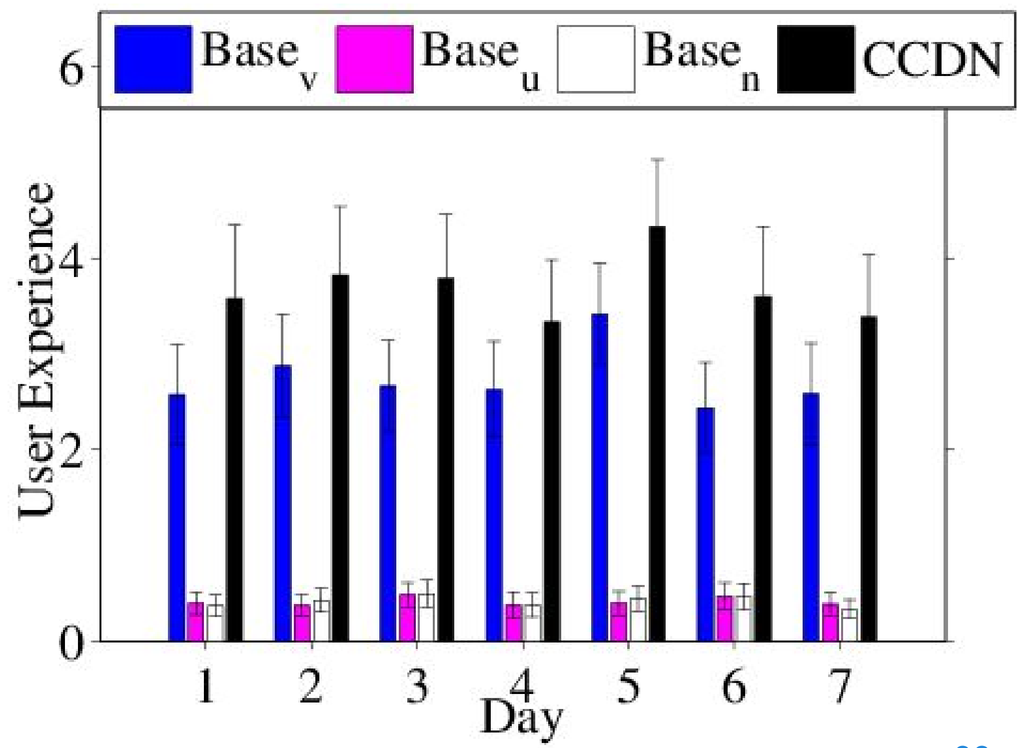
- Disk Budget: 60, 125, 250, 500 MB
- Energy Budget: 500, 1000, 2000, 4000 J
- WiFi power consumption: 600 mW in the range of 25 m
- The maximal segment size is 25 MB
- We set the user experience improvements of layers 1–3 to be 0.26, and the medium- and high-resolution videos to be 0.12 and 0.10

Baselines of CCDN Simulator

- Experience driven baseline ($Base_v$)
  - Greedily requests the unit with the **highest user experience improvement**
- User centrality driven baseline ($Base_u$)
  - Greedily sends the units to the mobile device with the **highest number of contacts**
- Throughput driven baseline ($Base_n$)
  - Greedily sends the units to the mobile device with the **best channel condition**

Service Quality: User Experience

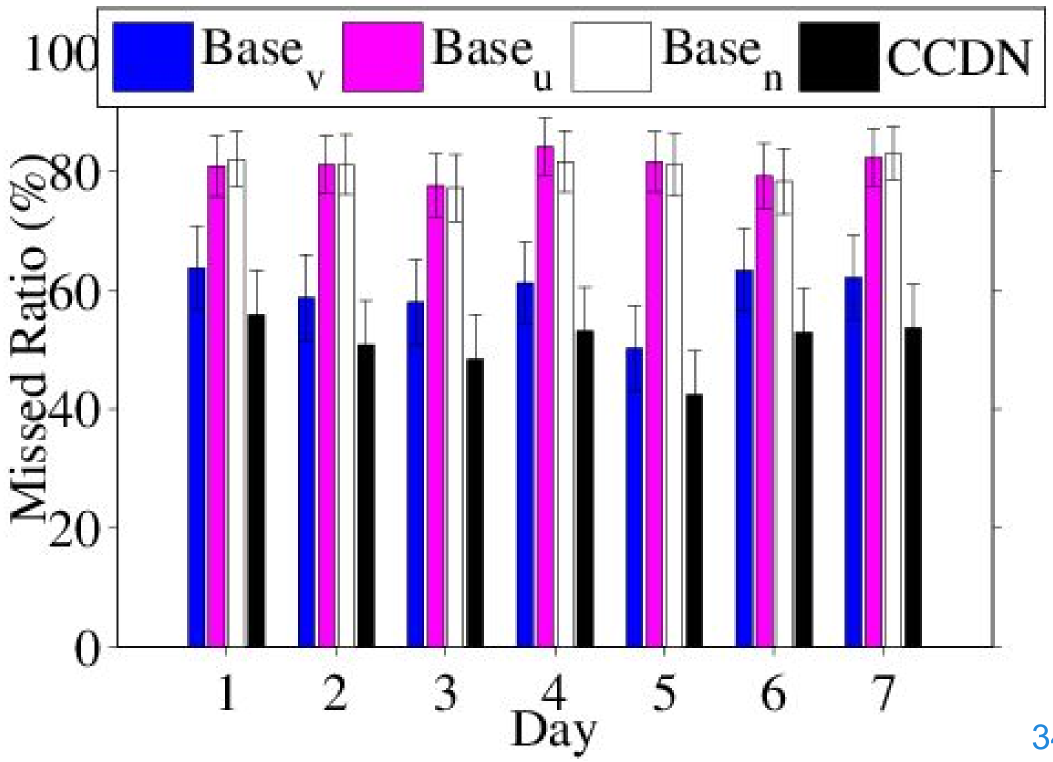
- CCDN outperforms 30% of $Base_v$, and overwhelms the other baselines
- CCDN considers more improvement of user experience compared to $Base_v$



Service Quality: Missed Ratio

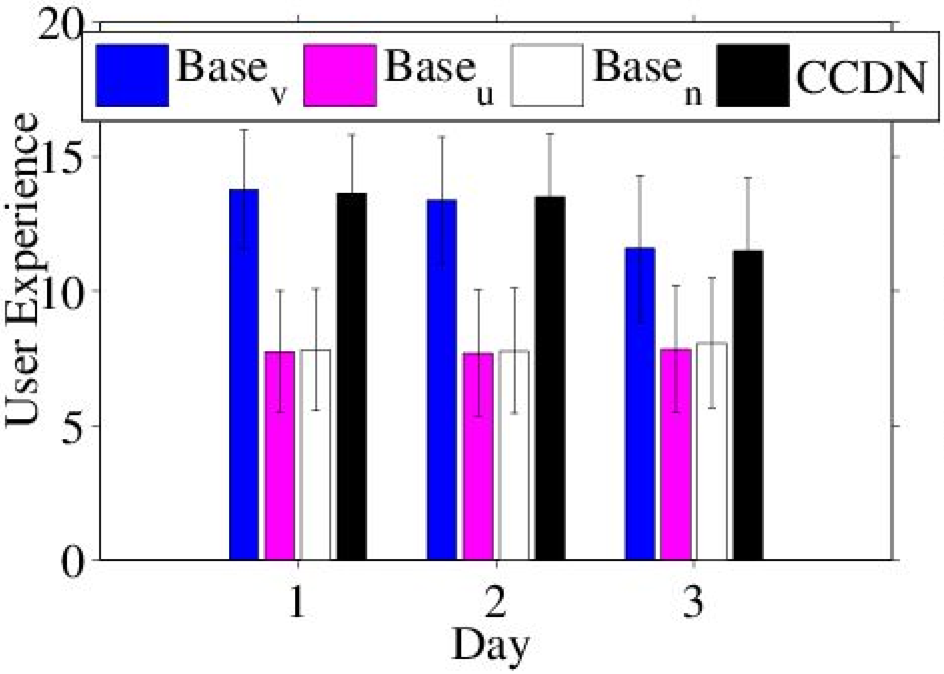
- The mobile users miss about 80% of new if $Base_u$ or $Base_n$ are used

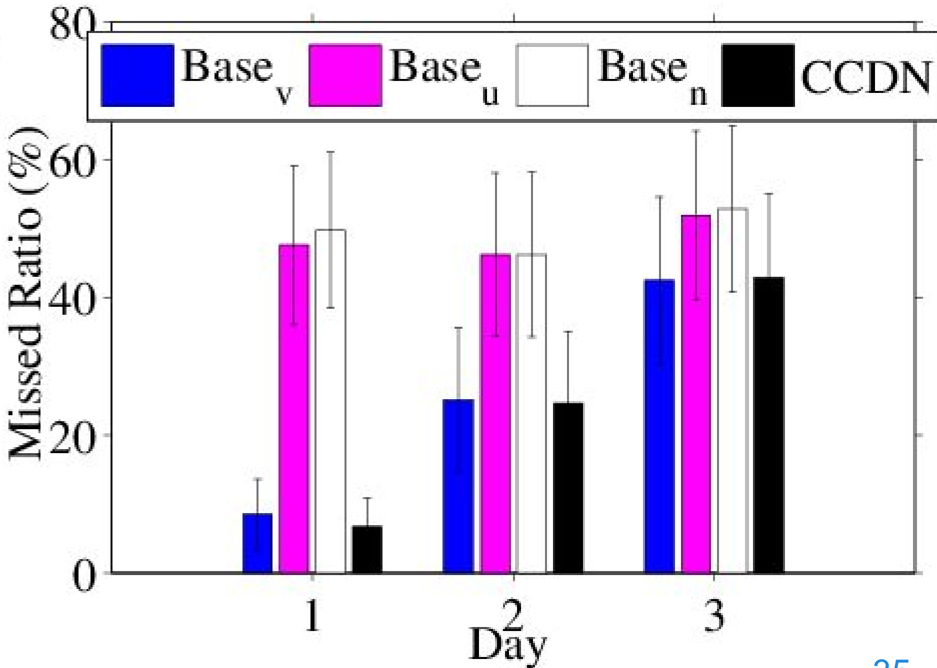
- CCDN has only 50% missed ratio and $Base_v$ is at most 10% worse than CCDN



Service Quality: SIGCOMM dataset

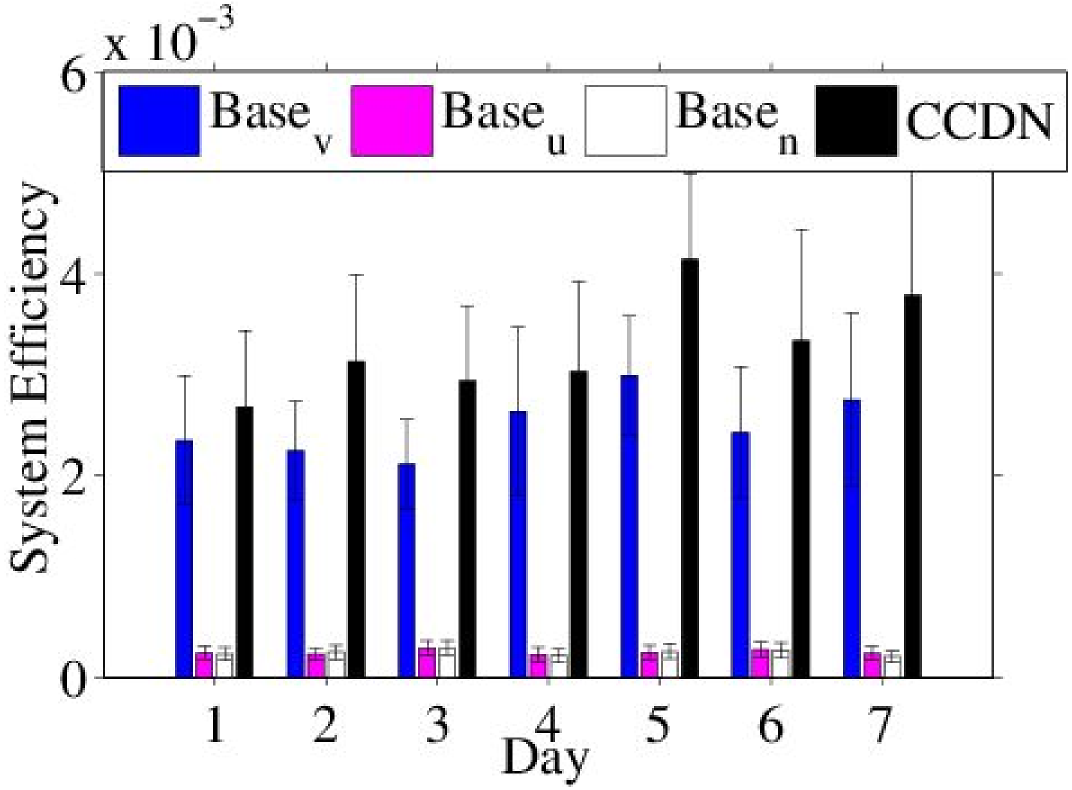
- The SIGCOMM dataset is so well-connected, user receive at least mid-resolution
- It leads to no optimization room for CCDN





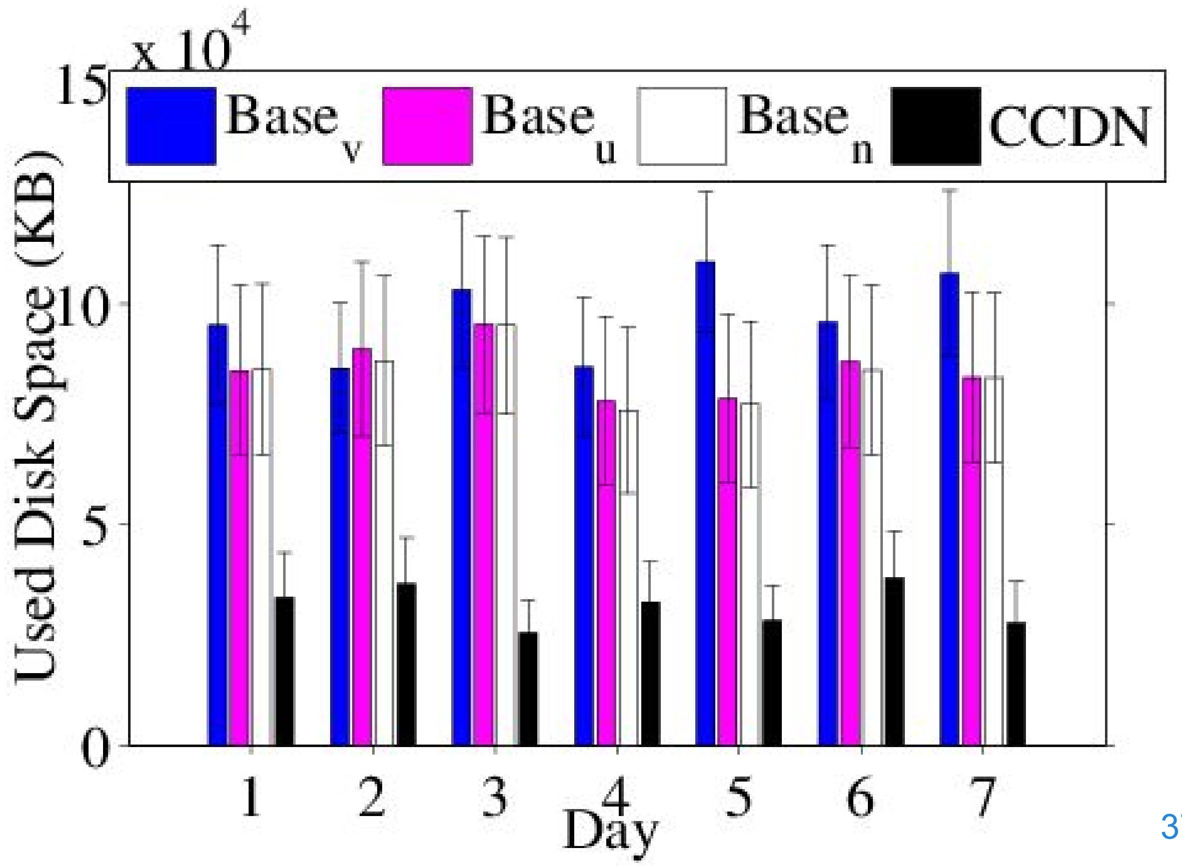
System Efficiency

- More than 10 times improvement compared to $Base_u$ and $Base_n$
- Up to 25% of improvement compared to $Base_v$



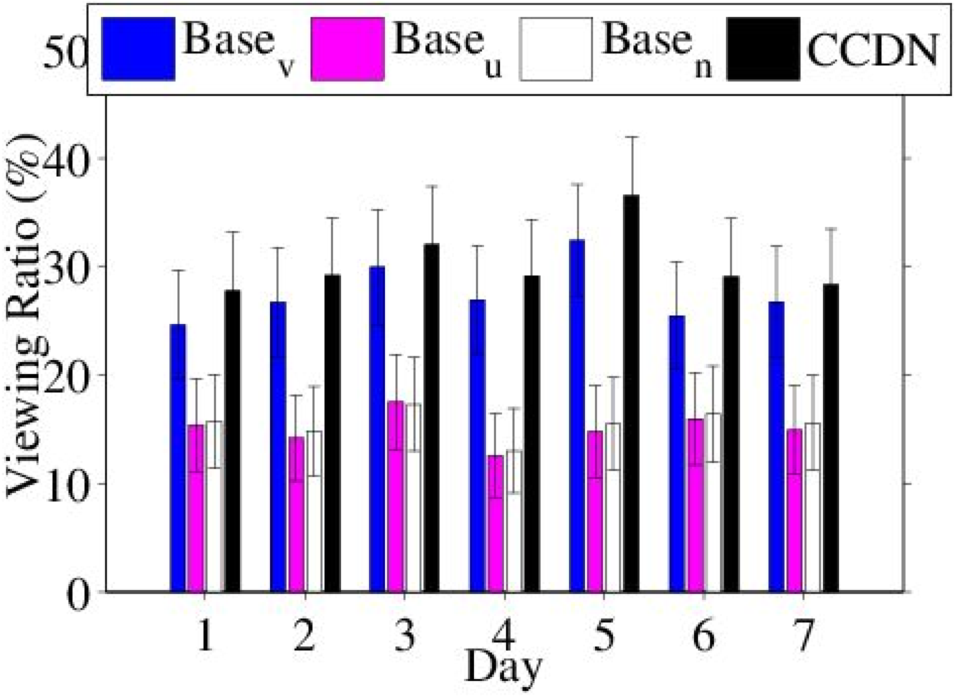
Resource Efficiency: Disk Space

- Our algorithm uses at most 1/3 of disk space, compared to all three baseline algorithms



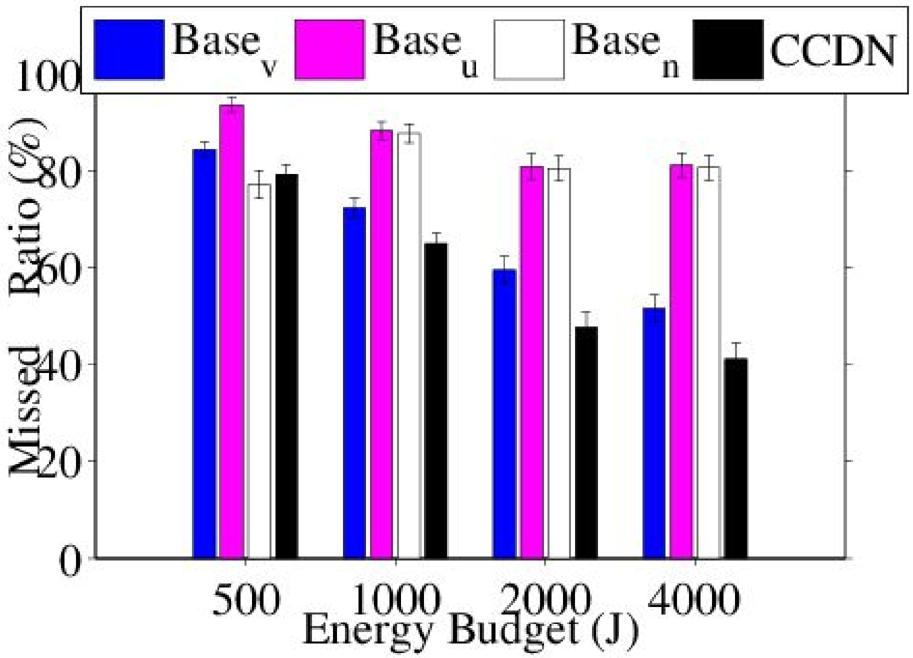
Resource Efficiency: Viewing Ratio

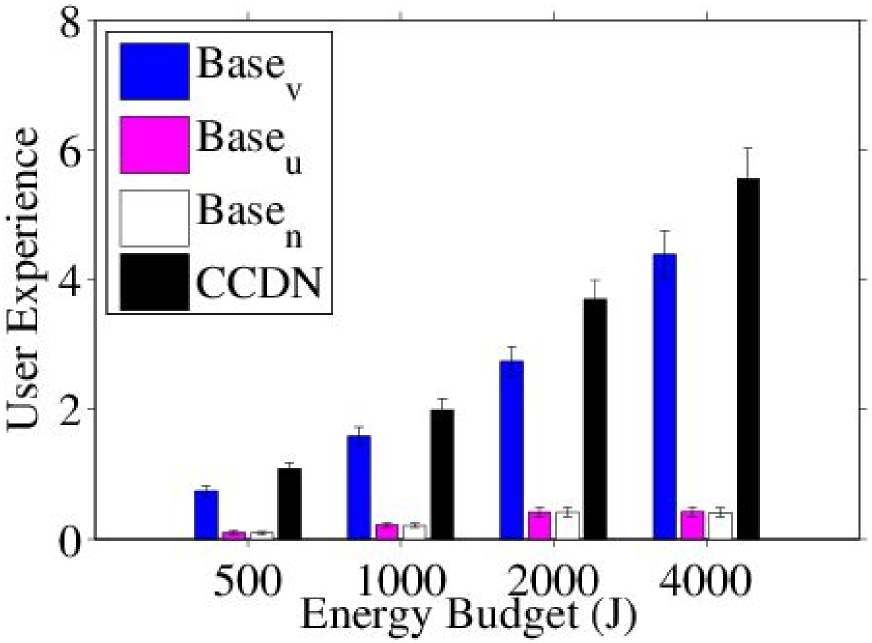
- Our CCDN wastes the least downloaded units
- $Base_u$ and $Base_n$ achieves less than 50% of viewing ratio of CCDN
- $Base_v$ is 5% lower than CCDN



Different Energy Budgets

- Our CCDN has the 5 times user experience gain and 50% miss ratio reduction

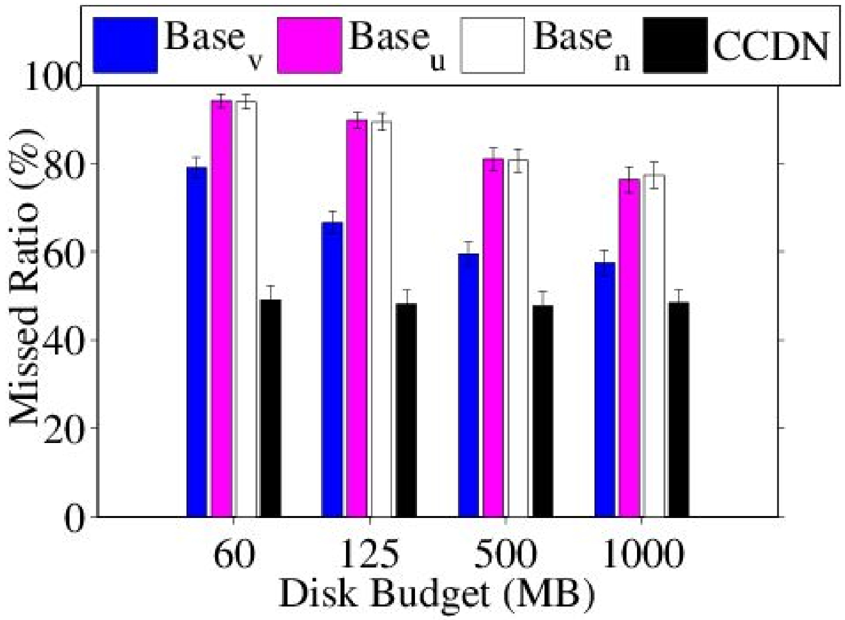


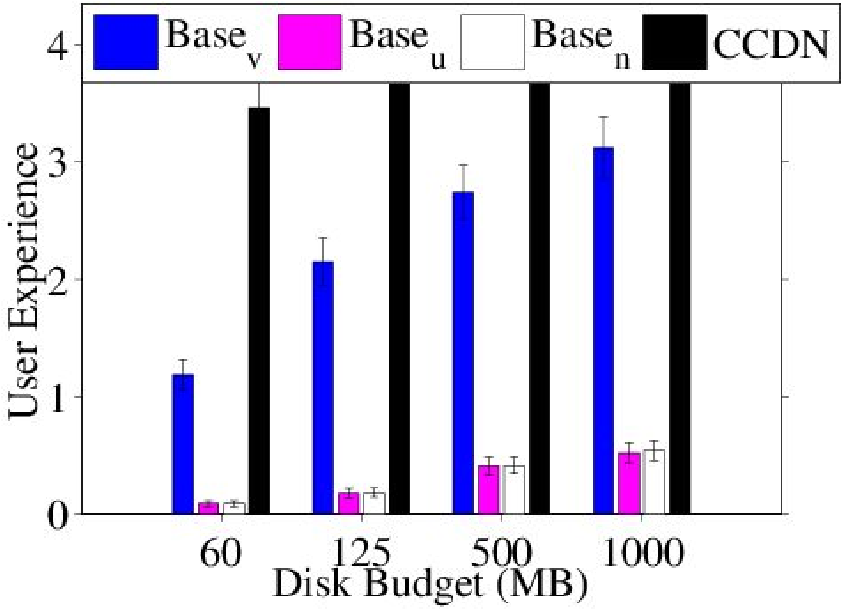


Different Disk Budgets

- Our CCDN achieves roughly the same service quality with growth of disk budget

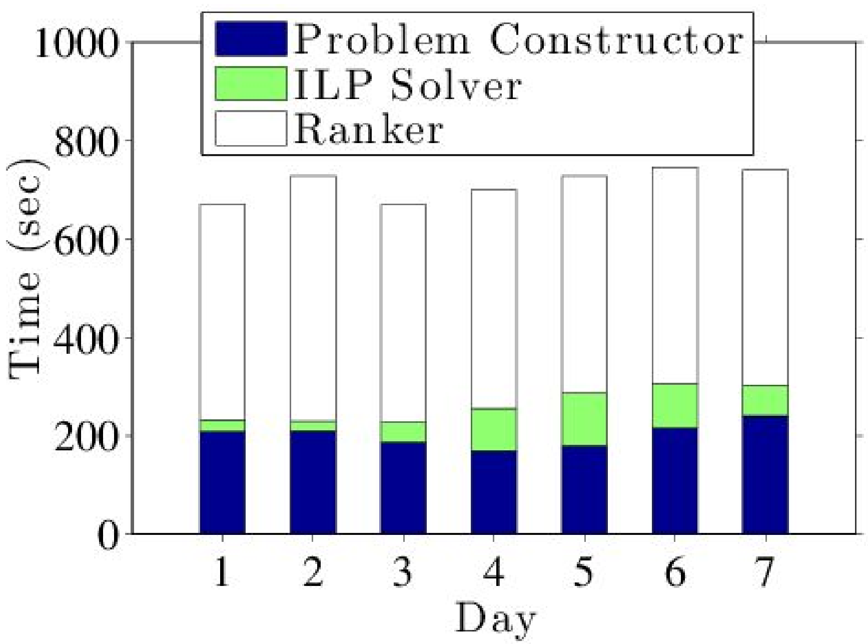
→ CCDN uses disk budget efficiently

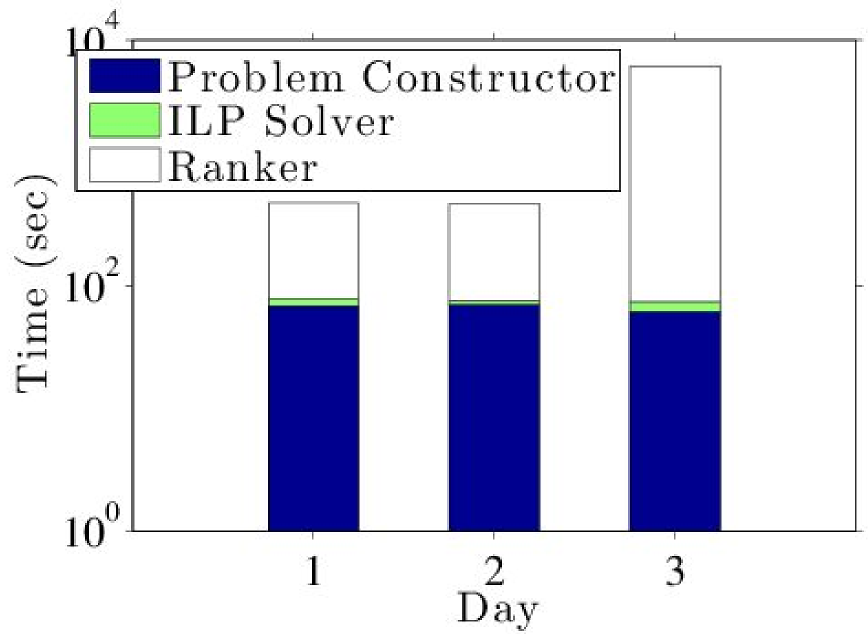




Running Time of CCDN

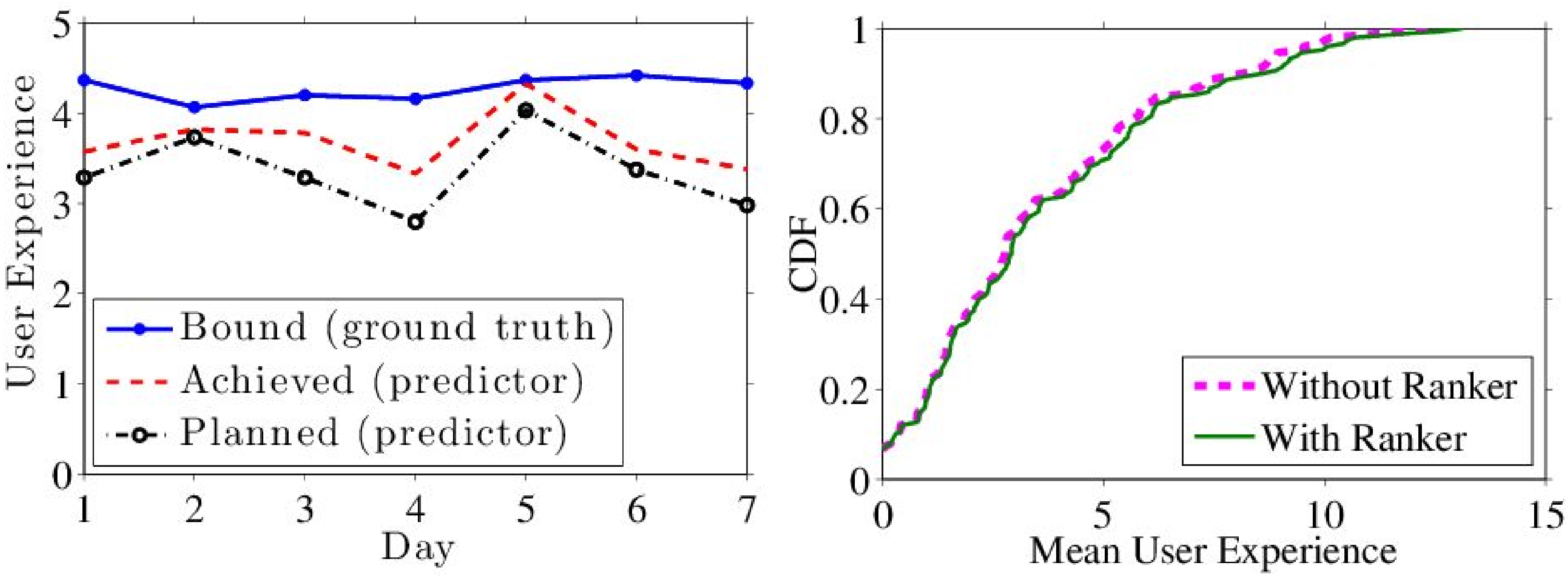
- The daily running times are 12 mins and 100 mins
- ILP solver runs fast, while ranker takes time





Machine Learning Algorithms

- Adaptive communication strategies works with user experience improvement
- The ranker requires fine tune on parameters



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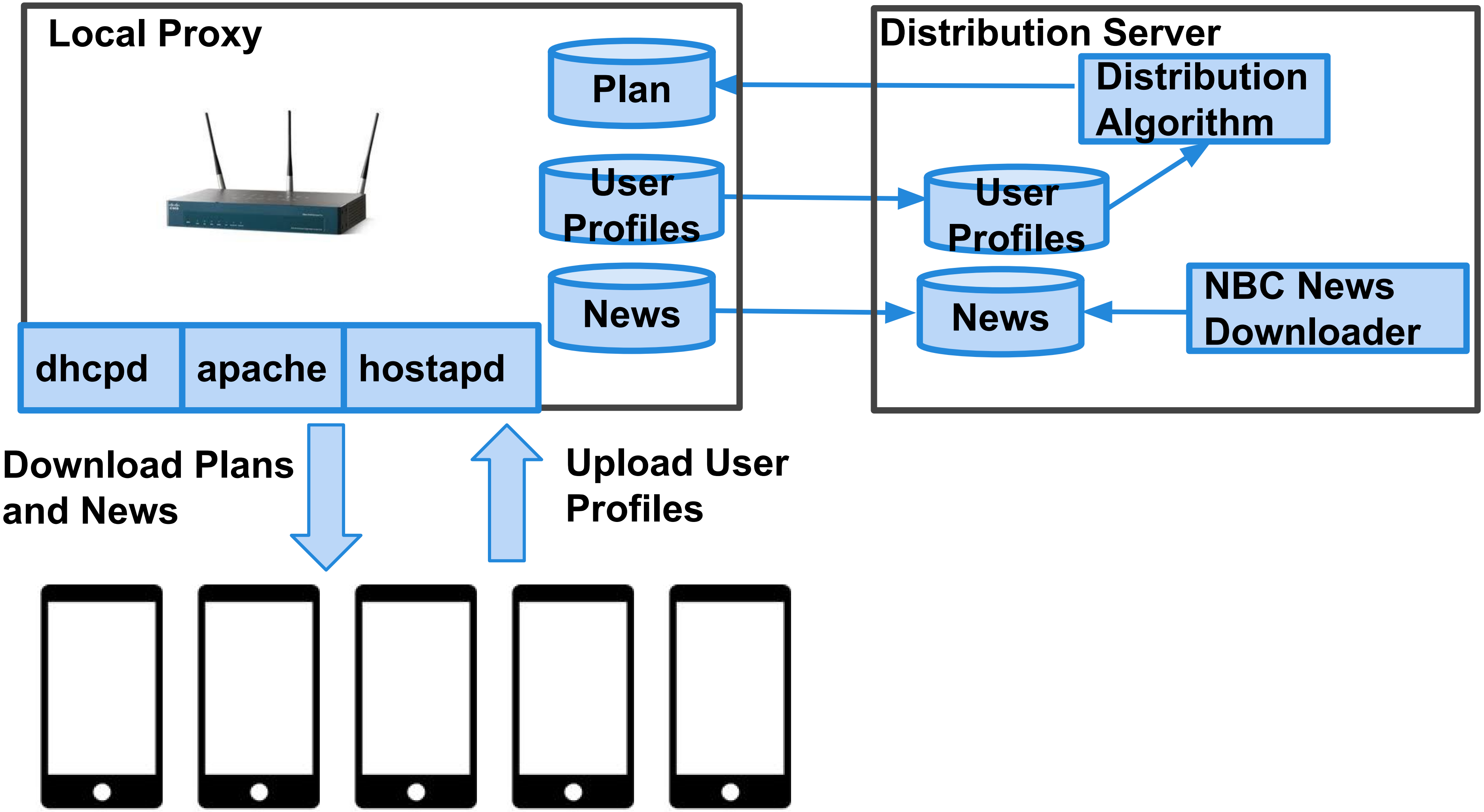
System Prototype Architecture

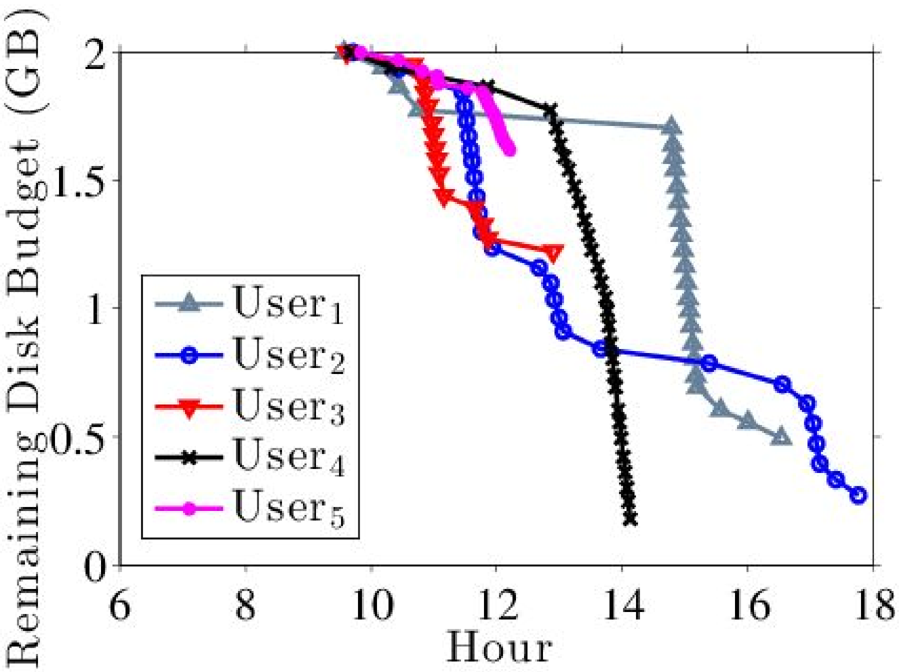


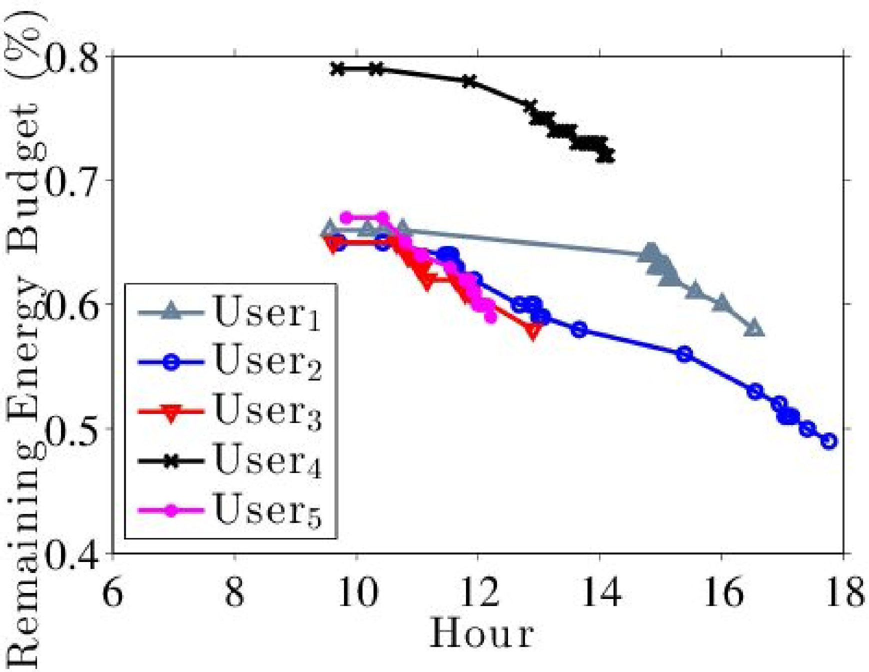
Experiment Setup

- Resource budget:
  - Disk: 2GB, 25% of the disk space
  - Energy budget: 6000 J 20% of the battery
- A distribution server and two local proxies are all on campus
- The distribution server sends the latest 300 news reports to local proxies everyday. Each news report has 5 layers, so we have 1500 units in total
- Mobile users refresh their news storage 5 a.m. everyday

Resource Consumption

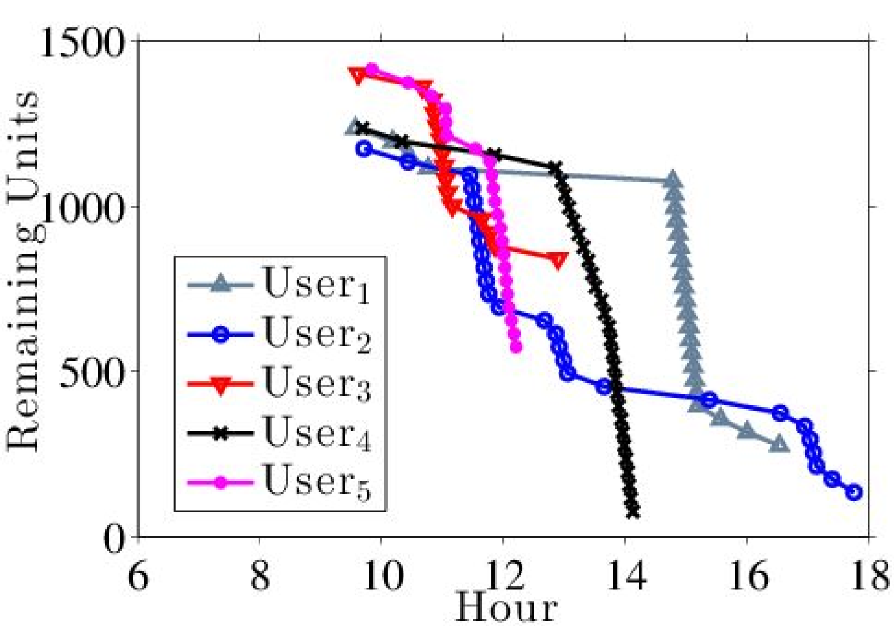
- Diverse network condition leads to different resource consumption

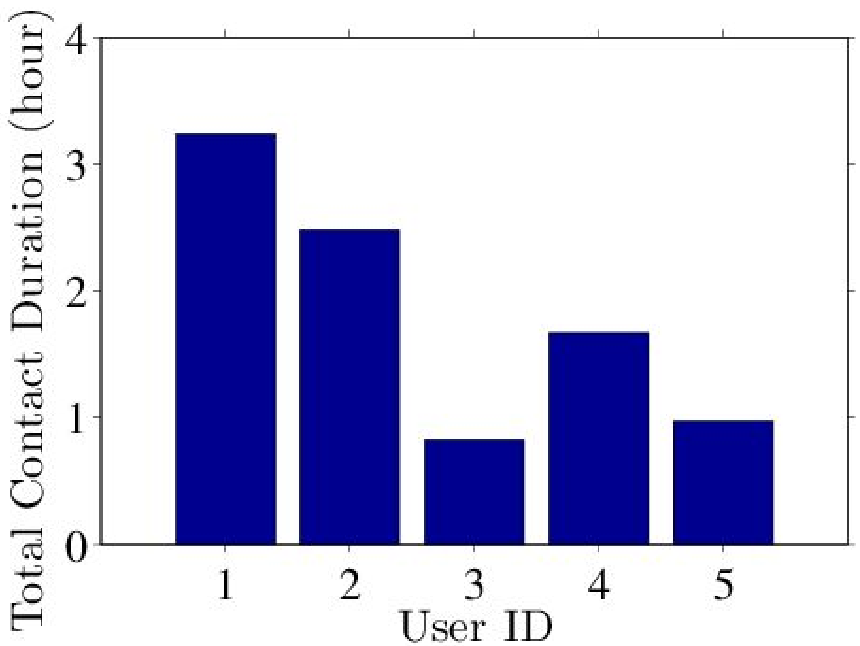




Contact Duration and Remaining Units

- Shorter contact duration leads to more remaining units





Prototype Limitations

- No units comes from smartphone peer
- Large videos require segmentation for efficient download
- A machine learning algorithm with appropriate parameters to support better adaptation among diverse users
- Make distribution server and local proxies may be in different geographic locations with diverse network conditions

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Conclusion

- We proposed a Challenged Content Delivery Network (CCDN), which carefully plans the distribution of news reports to mobile users
- CCDN outperforms the baseline algorithms by 55% to 10 times of user experience
- Achieves higher system efficiency than the baseline algorithms by 37% to 20 times
- Fast running time in 12 mins for 150 users

Q & A