MPBond: Efficient Network-level Collaboration Among Personal Mobile Devices

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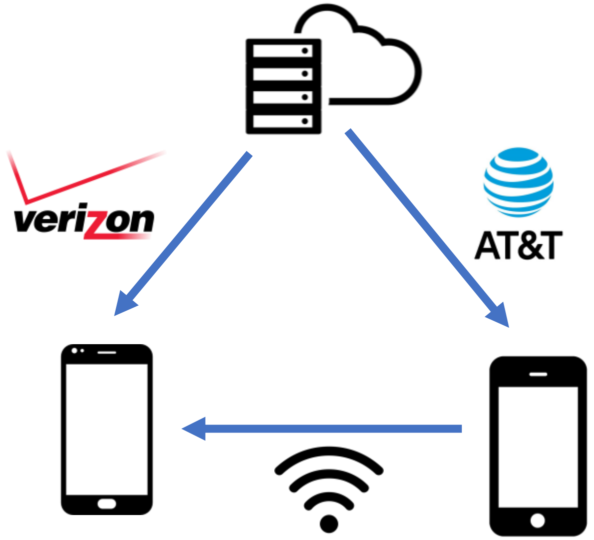
Ubiquitous Personal Mobile Devices

Multi-device ownership

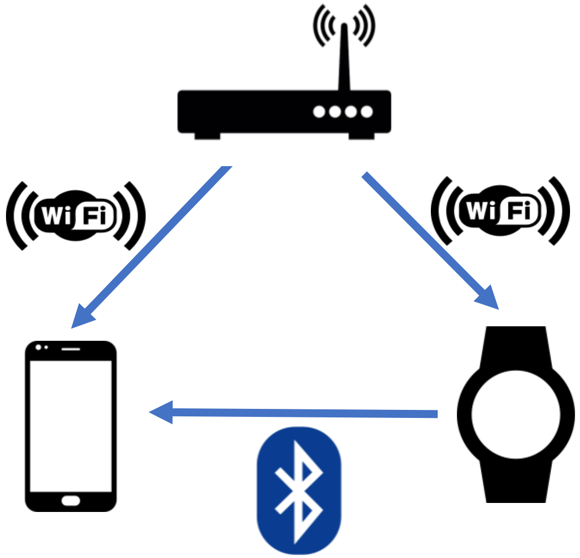
Group activities

Network-level Collaboration Helps!

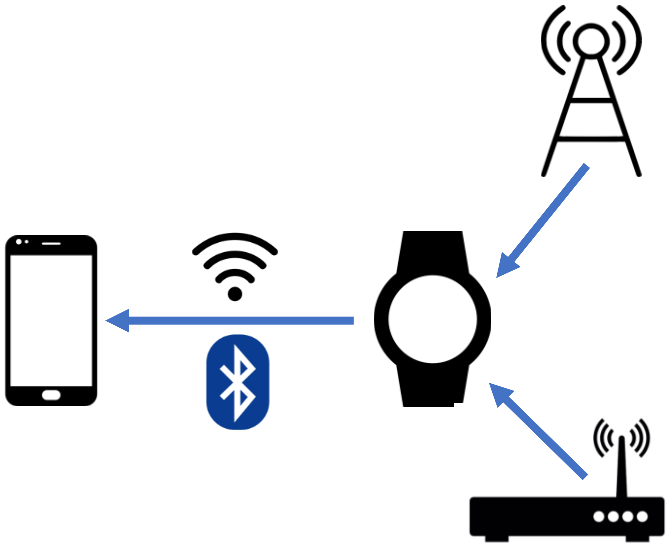
Improve throughput



Tackle per-device rate limit



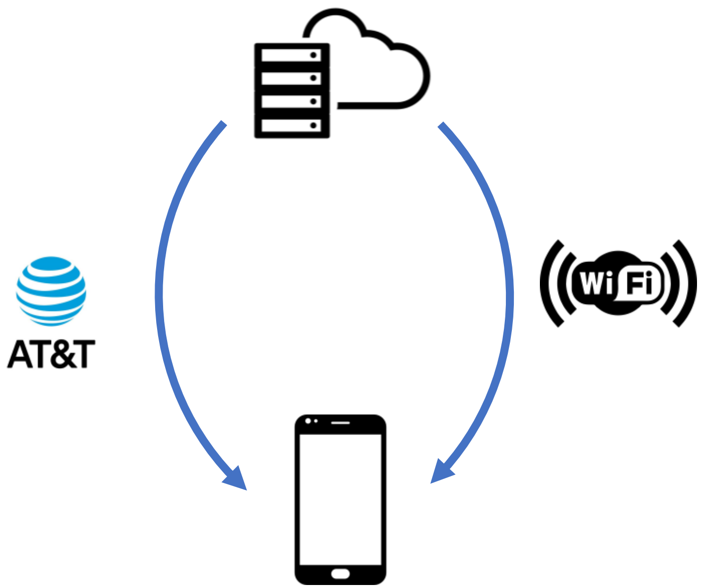
Extend wireless range



Need a software framework to bridge networking hardware ☺

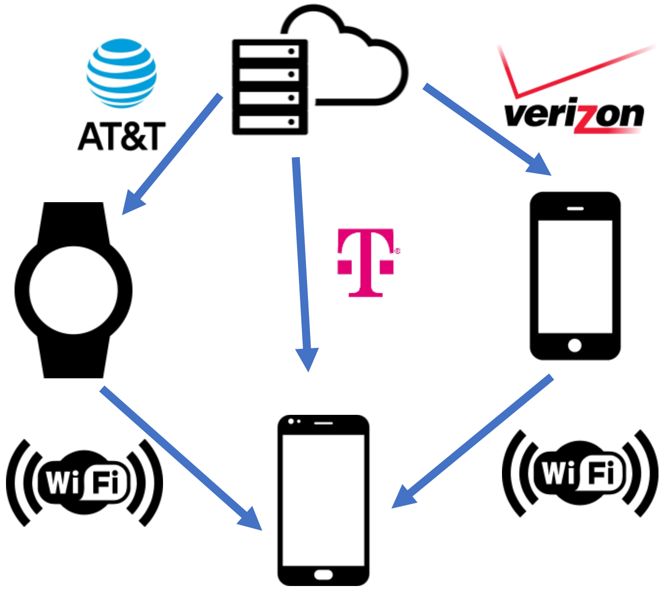
Collaboration Meets Multipath Transport

Simultaneous data transfers over multiple network paths (*aka*, subflows)



Traditional multipath transport (e.g., MPTCP)

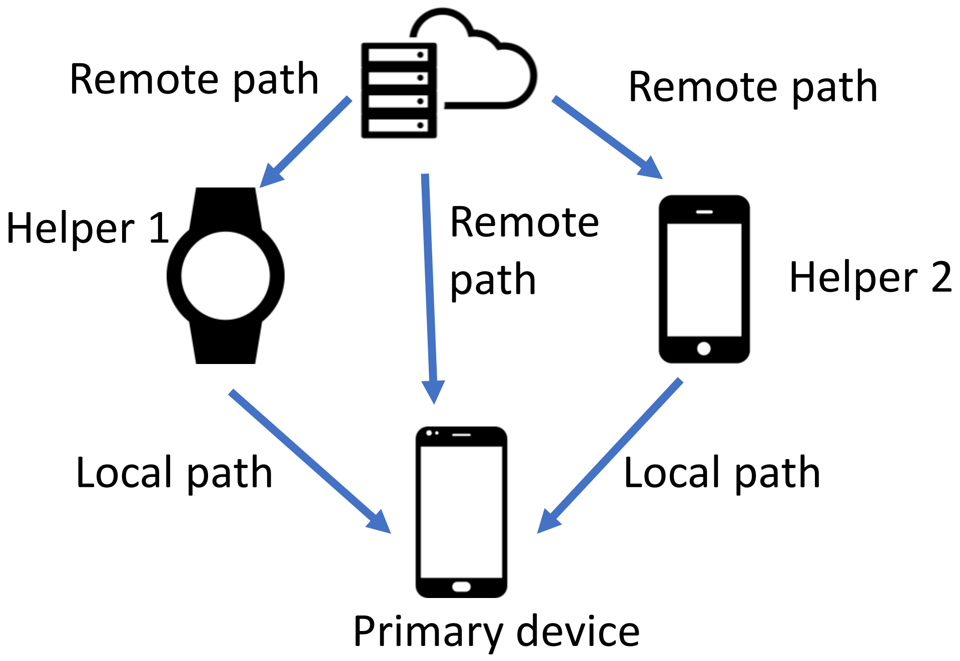
Subflows traverse multiple mobile devices



Need "distributed" multipath transport

Challenges for An Efficient Collaboration Scheme

- Proper management of heterogeneous devices and links
- Efficient leverage of helper devices to improve network performance
- Judicious distribution of data over remote and local paths
- Appropriate interfaces to apps and users
- Transparency of the scheme to client and server apps



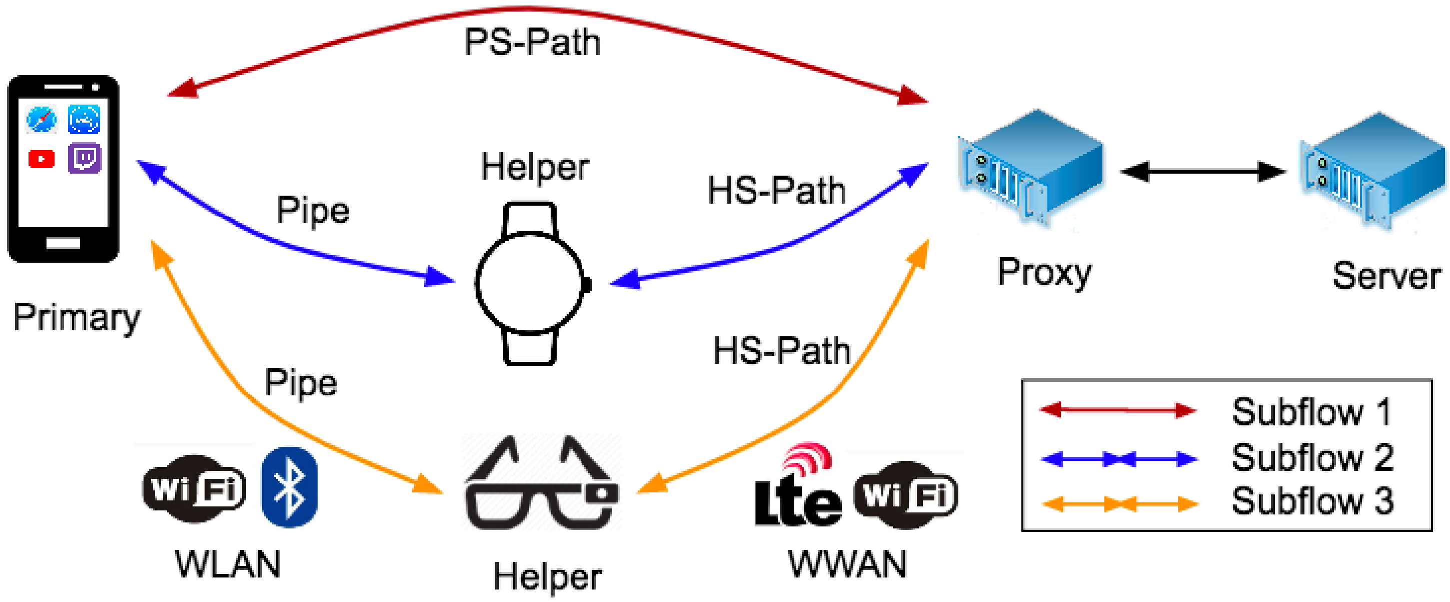
Existing Collaboration Schemes Fall Short

- Lack of flexibility
  - Tethering+MPTCP [1], inverse multiplexing [2]
  - Application modifications [3, 4, 5]
- Suboptimal Performance
  - Under fluctuating remote and local network conditions [1, 2]
  - Due to idle times incurred by chunk-based data distribution [3-5]
  - Due to suboptimal scheduling decisions [1-5]
- Excessive energy consumption
  - Long download time [1-5]
  - Prolonged remote or/and local link radio-on time [1-5]

[1] Using cooperation for low power low latency cellular connectivity, CoNEXT 2014
[2] Improving TCP performance over wireless networks with collaborative multi-homed mobile hosts, MobiSys 2005
[3] Combine: leveraging the power of wireless peers through collaborative downloading, MobiSys 2007
[4] MicroCast: Cooperative video streaming on smart-phones, MobiSys 2012
[5] Cool-tether: energy efficient on-the-fly wifi hot-spots using mobile phones, CoNEXT 2009

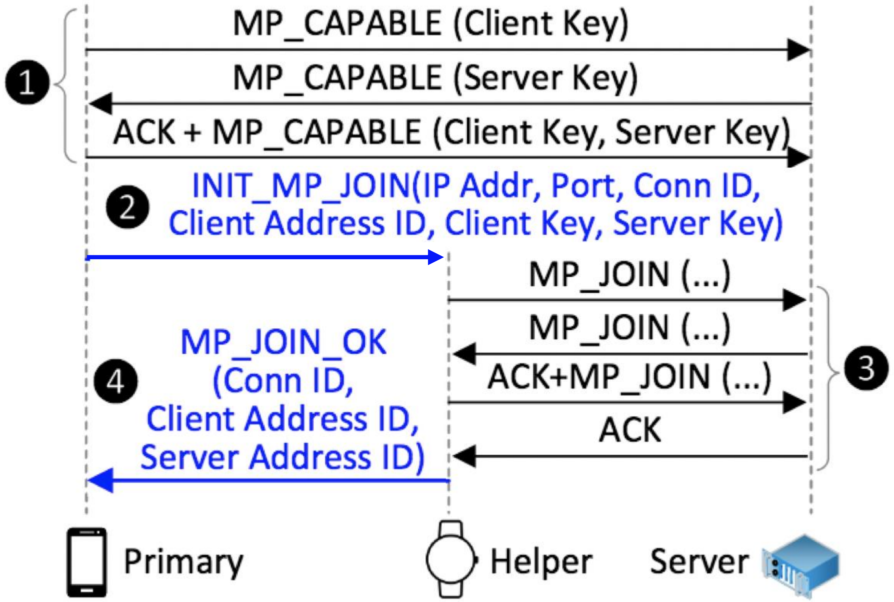
Our Solution: MPBond

A distributed multipath transport system for efficient network-level collaboration



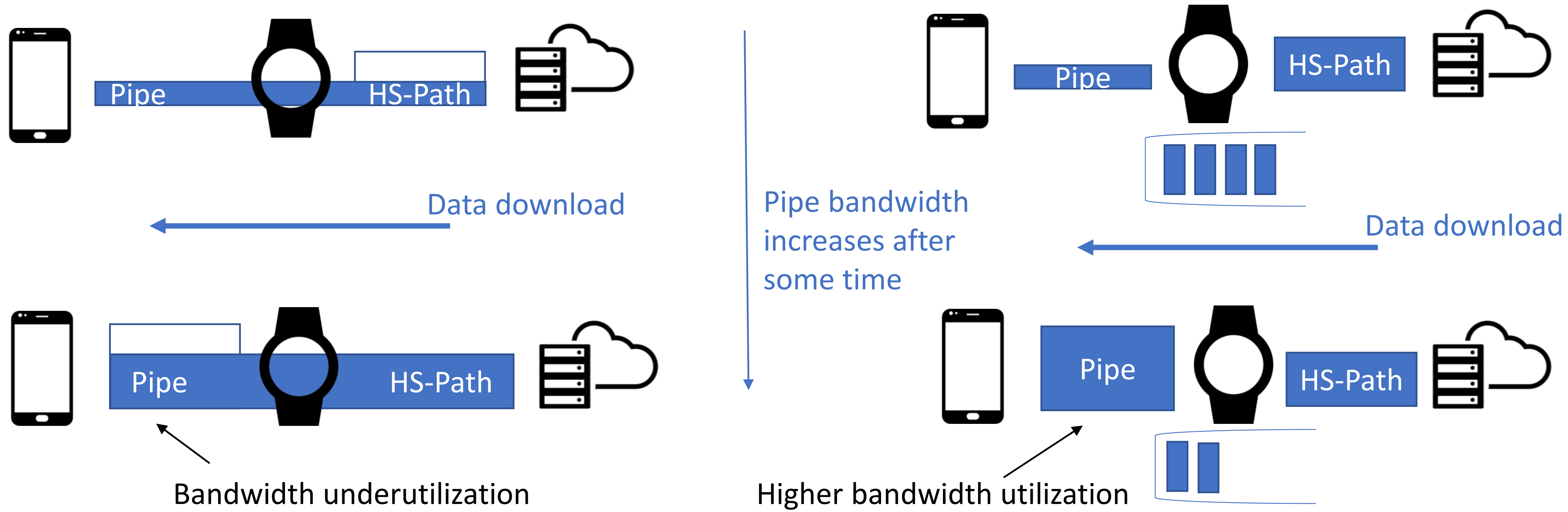
Subflow Management

- Primary-centric pipe establishment to reduce helper-primary hop count
- Handshake is similar to MPTCP but with additional control messages over the pipe



Buffer Management and Connection Split

w/o TCP split and buffering v.s. w/ TCP split and buffering

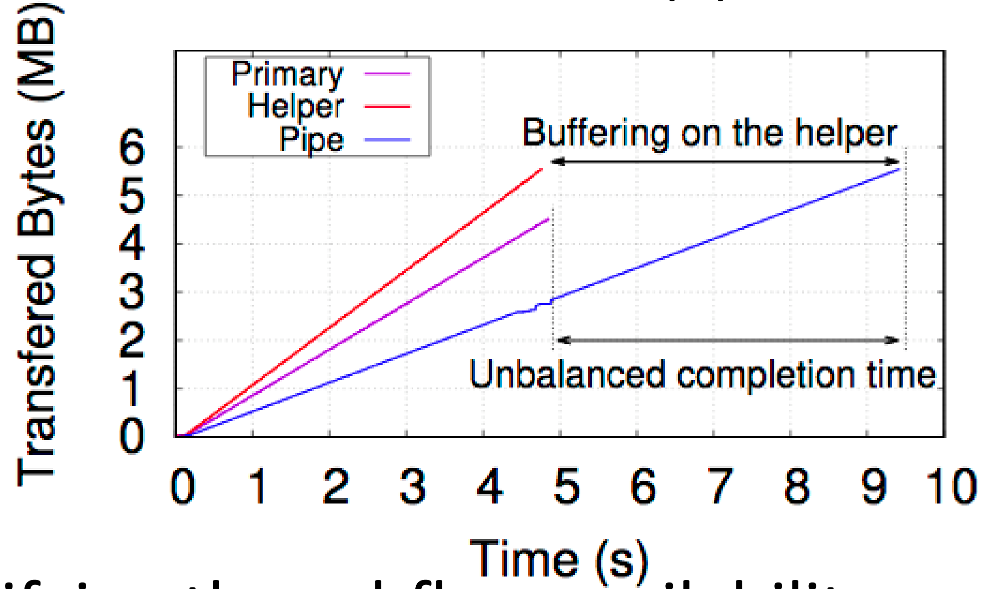


Data Distribution over Multiple Paths

- Realized by a multipath scheduler
- Optimal multipath scheduling requires simultaneous data completion at the receiver
- MinRTT is the default scheduler for MPTCP by selecting the path with available space in congestion window (cwnd) and the minimum RTT

Why Not the Default MinRTT Scheduler?

- MinRTT fails to achieve simultaneous subflow completion in MPBond
  - Due to the lack of consideration of the pipe

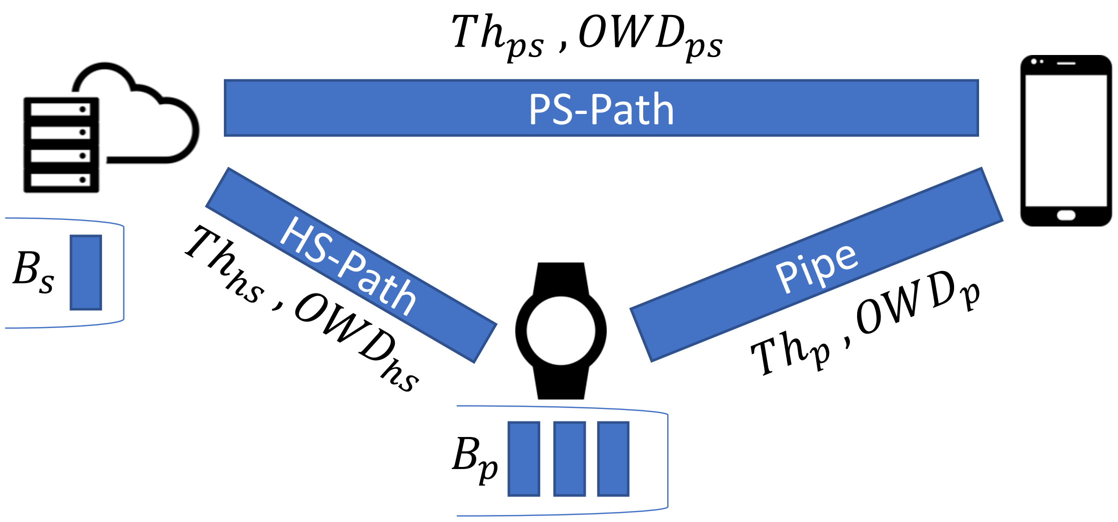


How about modifying the subflow availability condition?

- Would lose the capability of buffering

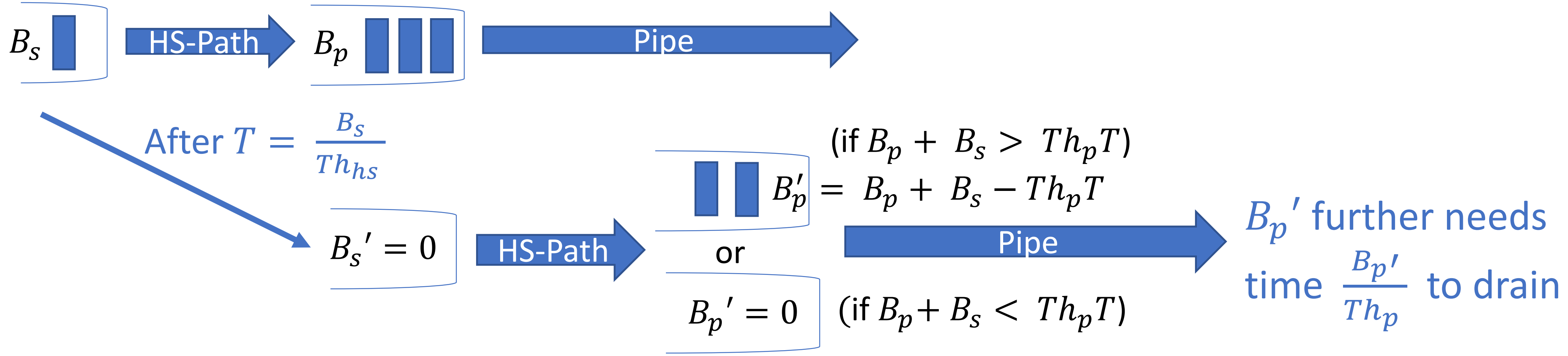
Pipe-aware Multipath Scheduler (PAMS)

- Challenge: enable buffering at the helper while achieving simultaneous subflow completion
- Making packet arrival time estimation pipe-aware
  - Pipe-aware delay: The time it takes for a packet scheduled over a given subflow at a given time to arrive at the receiver



Deriving the Pipe-aware Delay (PAD)

- PAD of the direct subflow (PAD_1) : $OWD_{ps} + \frac{B_s}{Th_{ps}}$
- For an indirect subflow (PAD_i , $i > 1$)



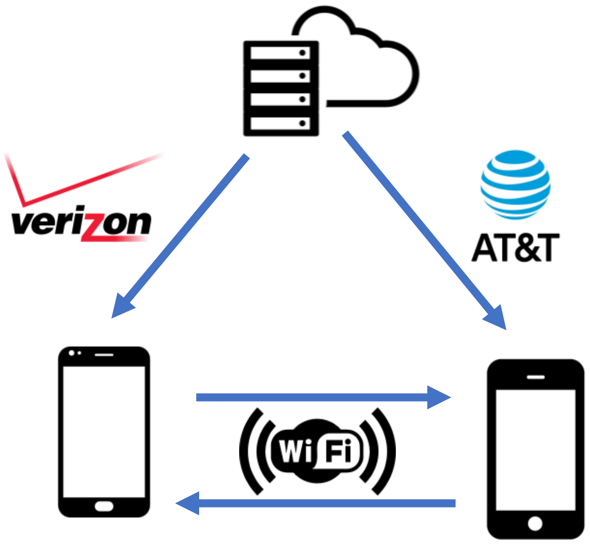
$$PAD_i = \begin{cases} OWD_{ps} + \frac{B_s}{Th_{ps}}, & \text{if } i = 1 \\ OWD_{hs} + \frac{B_s + B_p}{Th_p} + OWD_p, & \text{if } i > 1, \frac{B_p}{B_s} + 1 > \frac{Th_p}{Th_{hs}} \\ OWD_{hs} + \frac{B_s}{Th_{hs}} + OWD_p, & \text{if } i > 1, \frac{B_p}{B_s} + 1 \le \frac{Th_p}{Th_{hs}} \end{cases}$$

The PAMS Algorithm

- Leverage PAD to make scheduling decisions
  - $minPAD$: select the path with available space in cwnd and minimum PAD
    - Useful when there is large amount of remaining data to send (Case 1)
  - When there is only small amount of remaining data (Case 2)?
    - Defer the scheduling!
  - Data Reinjection

User/App Interfaces and Policy Engine

- Users
  - Per-app whitelist, resource usage, prioritization
- Apps
  - Optional APIs for device/pipe monitoring and management
- Dual mode



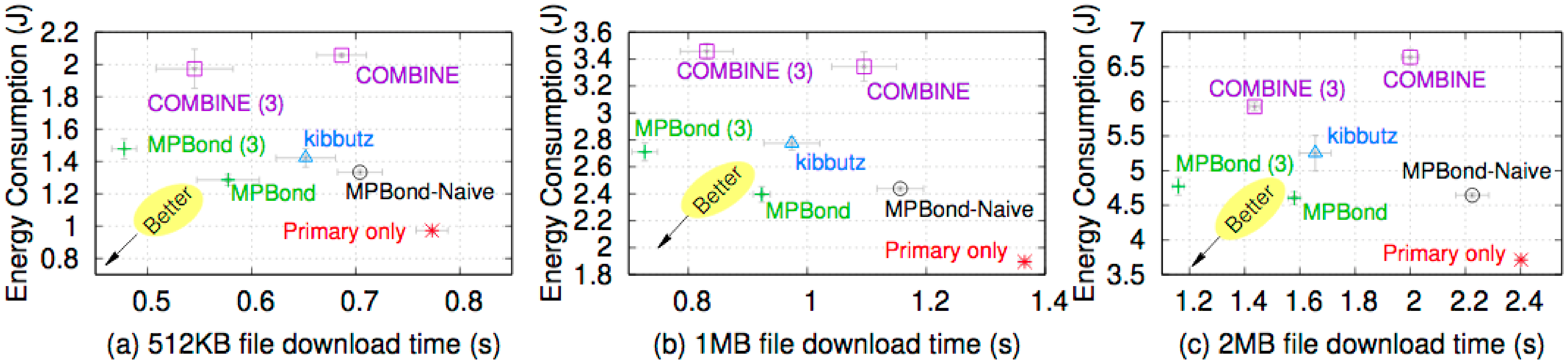
Evaluation

- MPBond prototype on Android smartphones and smartwatches
- Comparison baselines
  - Single device, kibbutz [1], COMBINE [2]
- Evaluation setup
  - Applications: file download, video streaming
  - Networks: emulated (with tc) and real WiFi and LTE
  - Devices: smartphones (Pixel 2, Nexus 6P) and a smartwatch (LG Urbane 2nd)

[1] Using cooperation for low power low latency cellular connectivity, CoNEXT 2014
[2] Combine: leveraging the power of wireless peers through collaborative downloading, MobiSys 2007

Evaluation: Stable network conditions

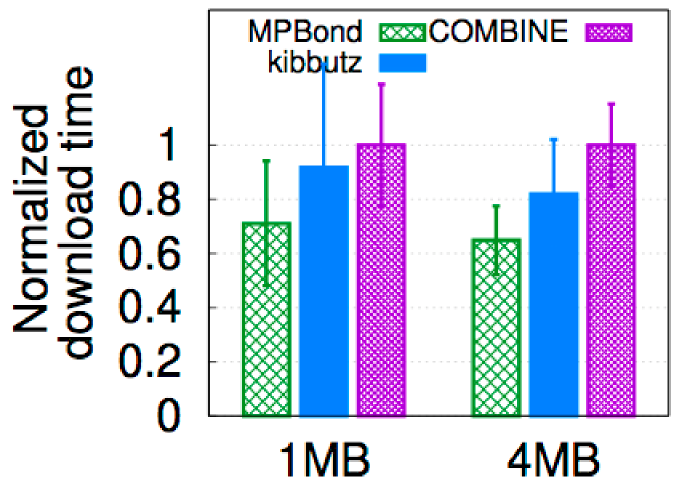
- File download
  - Primary: Pixel 2, Helper 1: Nexus 6P, Helper 2: LG Urbane 2nd
  - PS-Path: 8Mbps, HS-Path: 10Mbps, pipe: 5Mbps

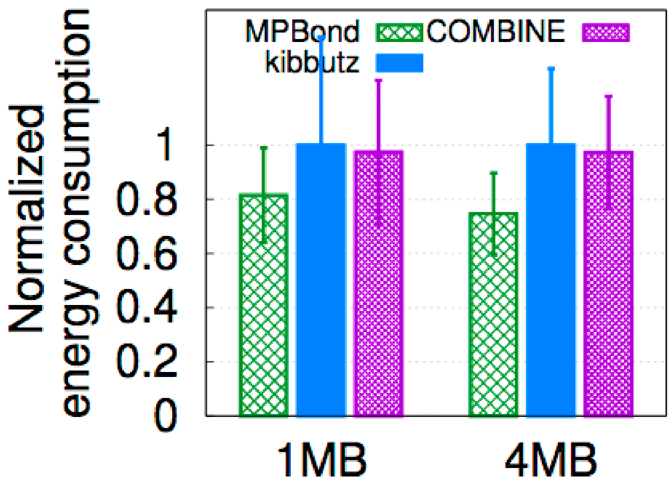


1. Using more devices reduces download time, with reasonable increase of total energy
2. MPBond reduces energy and download time compared to kibbutz and COMBINE

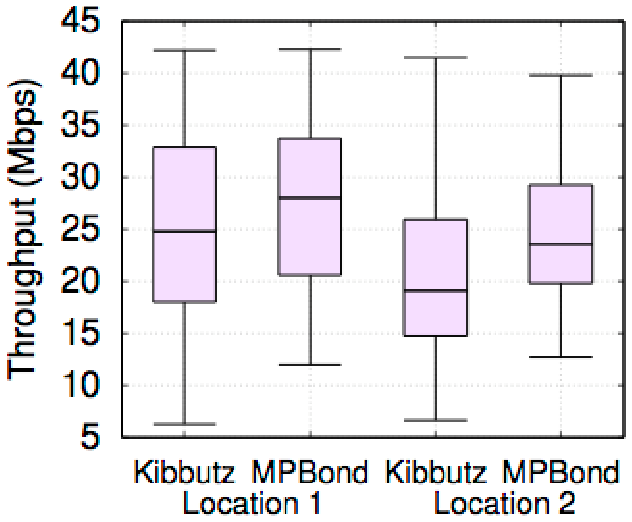
Evaluation: Varying network conditions

Replay real WiFi and LTE bandwidth traces





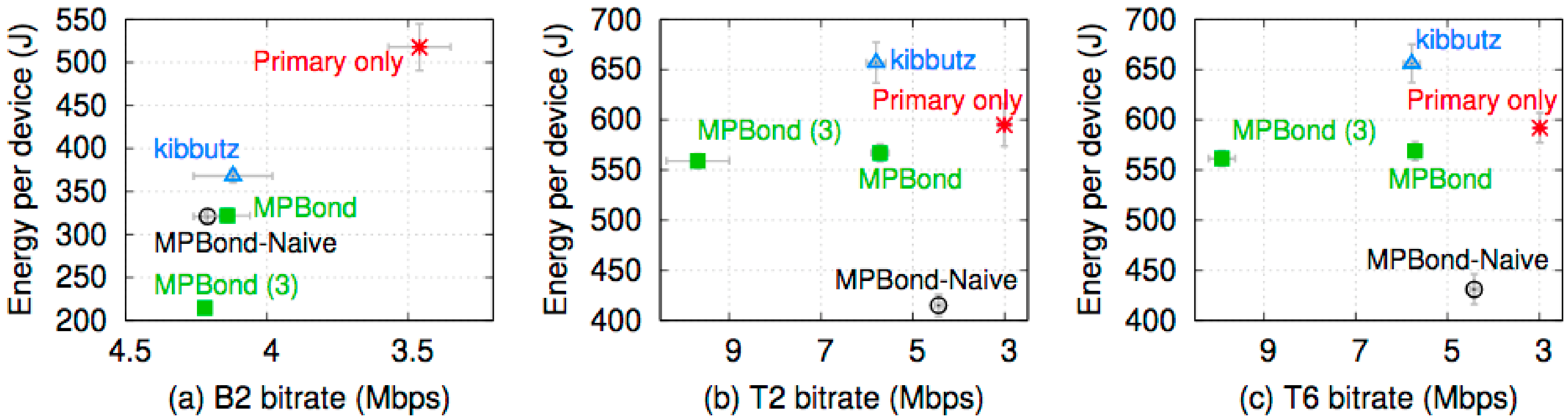
In-the-wild experiments



MPBond reduces the file download time by 13%-35%, which also translates to lower energy consumption, compared to kibbutz and COMBINE

Evaluation: Video streaming

- Three video sources: Big Buck Bunny w/ 2-sec segments (B2), Tears of Steel w/ 2-sec segments (T2) and 6-sec segments (T6)
- PS-Path: 5Mbps, HS-Path: 10Mbps, pipe: 5Mbps



1. MPBond reduces energy consumption compared to kibbutz with same # of devices
2. With 3 devices, MPBond improves the video bitrate by up to 118% compared to kibbutz

Conclusion

- Mobile devices need network-level collaboration
- Collaboration made efficient & easy by MPBond
  - Distributed multipath transport
  - Device, connection, and buffer management
  - Judicious pipe-aware scheduling
- MPBond prevails over existing collaboration schemes
  - Performance, energy efficiency, and flexibility

Thank you! Questions?