WearDrive: Fast and Energy Efficient Storage for Wearables

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† Georgia Tech   Microsoft

Wearable Computing: A New Era

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Notifications Fitness/Healthcare Audio/Video Data Analytics

Wearables Are Battery Constrained

+

1.5 - 2.5K mAh

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f (Size & Weight)

100 – 500 mAh

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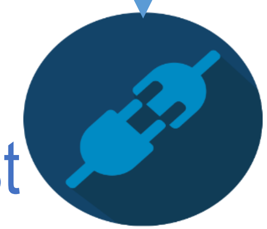
Mobile SoC,
OS & SDK

f (Size & Weight)

Reduce
Development Cost



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Wearable SoC,
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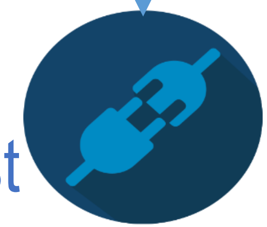

Wearable SoC,
OS & WearSDK

Offload Wearable's Workload to the Phone

Energy Challenge: Wearable Apps Are Data-Intensive

Extended Display

Notifications

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Sensors

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16+ Sensors

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Fast & Energy-Efficient Storage System

Notifications

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16+ Sensors

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Mobile Storage is Energy-Intensive

Flash device is not energy-intensive,

Storage software stack is energy-intensive !

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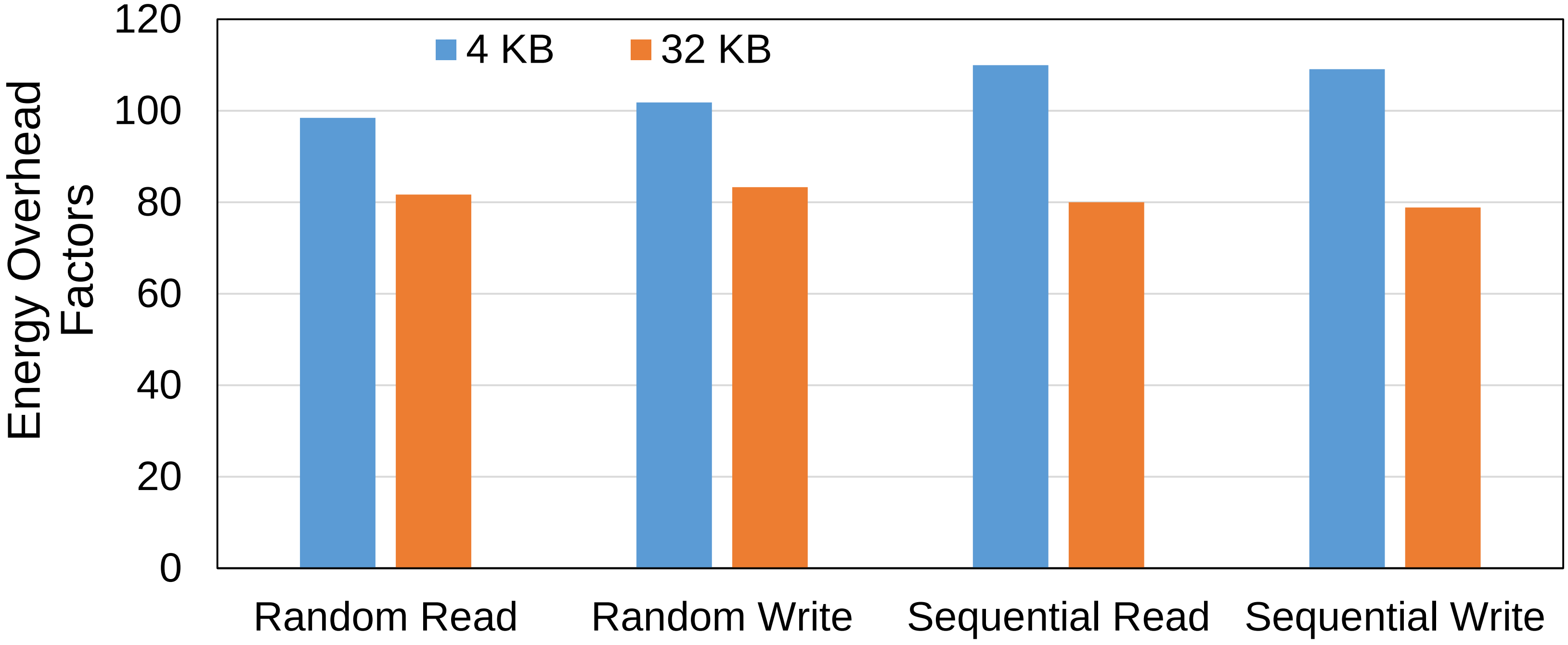


Storage software consumes 80–110x more energy than Flash [Li et al., FAST'14]

Mobile Storage is Energy-Intensive

Flash device is not energy-intensive,

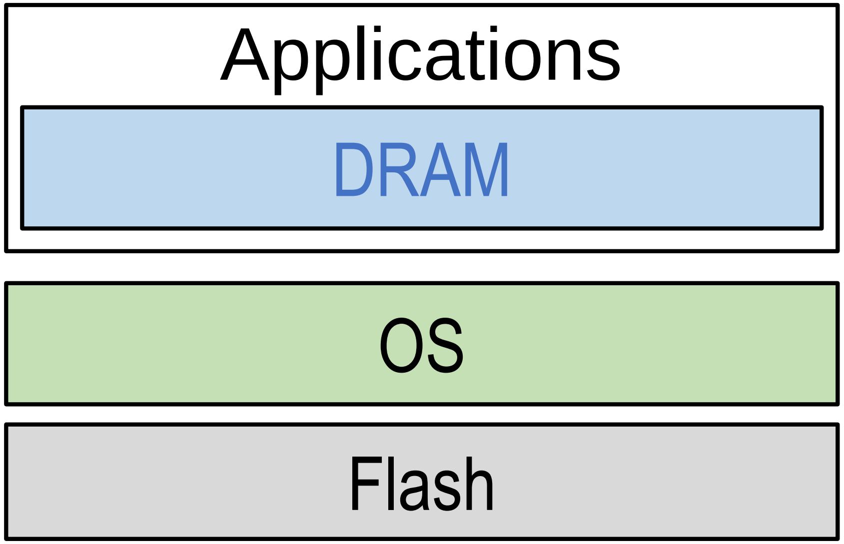
Storage software stack is energy-intensive !

Slow Flash:
Increased CPU Idle Time

Runtime System
Overhead

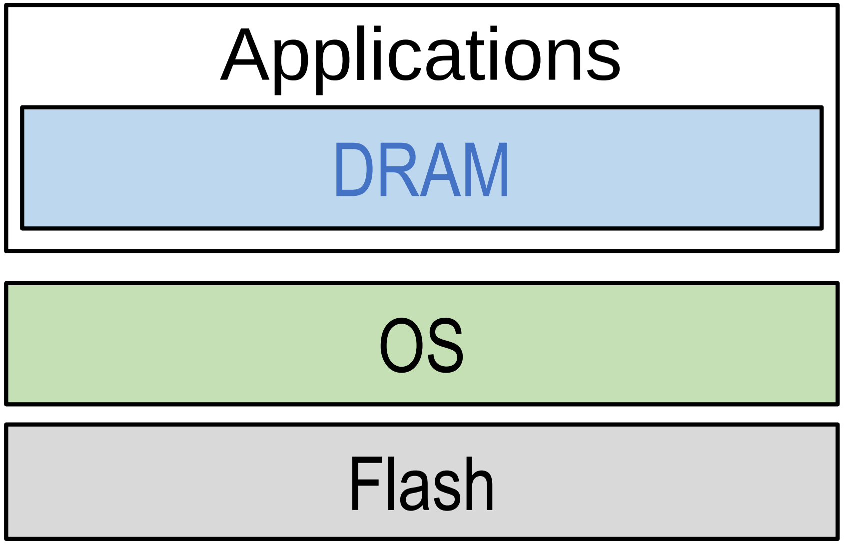
Data
Encryption

Use DRAM as Storage?



- DRAM is fast
- Closer to applications
- No software overhead for isolation and security

Use DRAM as Storage?



- DRAM is fast
- Closer to applications
- No software overhead for isolation and security

DRAM is volatile, the data durability is a problem !

Leveraging Batteries for Non-Volatility

DRAM

Battery

=

Non-Volatile Memory

Leveraging Batteries for Non-Volatility

DRAM

Battery

BB-RAM

=

Non-Volatile Memory

Leveraging Batteries for Non-Volatility

DRAM

Battery

BB-RAM

= Non-Volatile Memory

No Hardware Changes

Leveraging Batteries for Non-Volatility

DRAM

Battery

BB-RAM

=

Non-Volatile Memory

No Hardware Changes

+

Performance Improvement

Leveraging Batteries for Non-Volatility

DRAM

Battery

BB-RAM

=

Non-Volatile Memory

No Hardware Changes

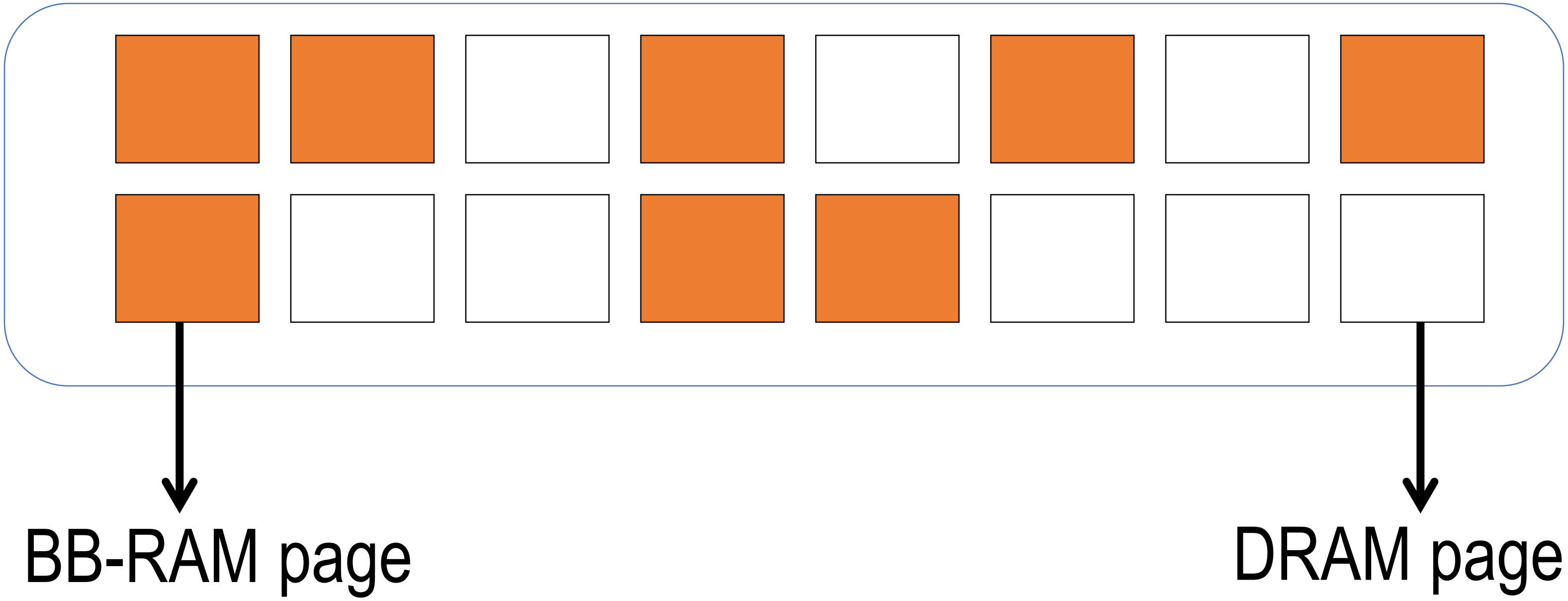
+

Performance Improvement

+

Data Durability

Our BB-RAM Implementation



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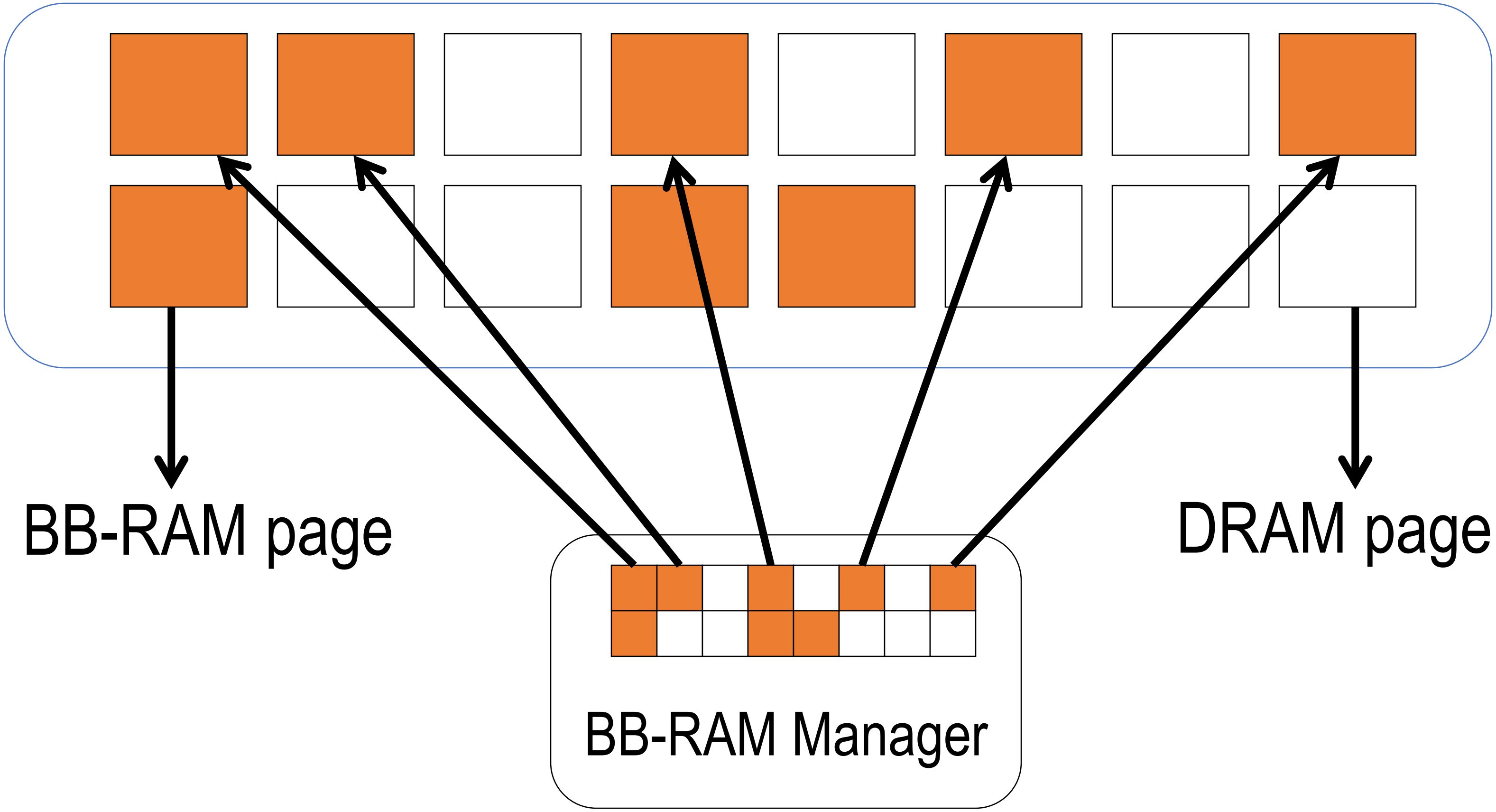

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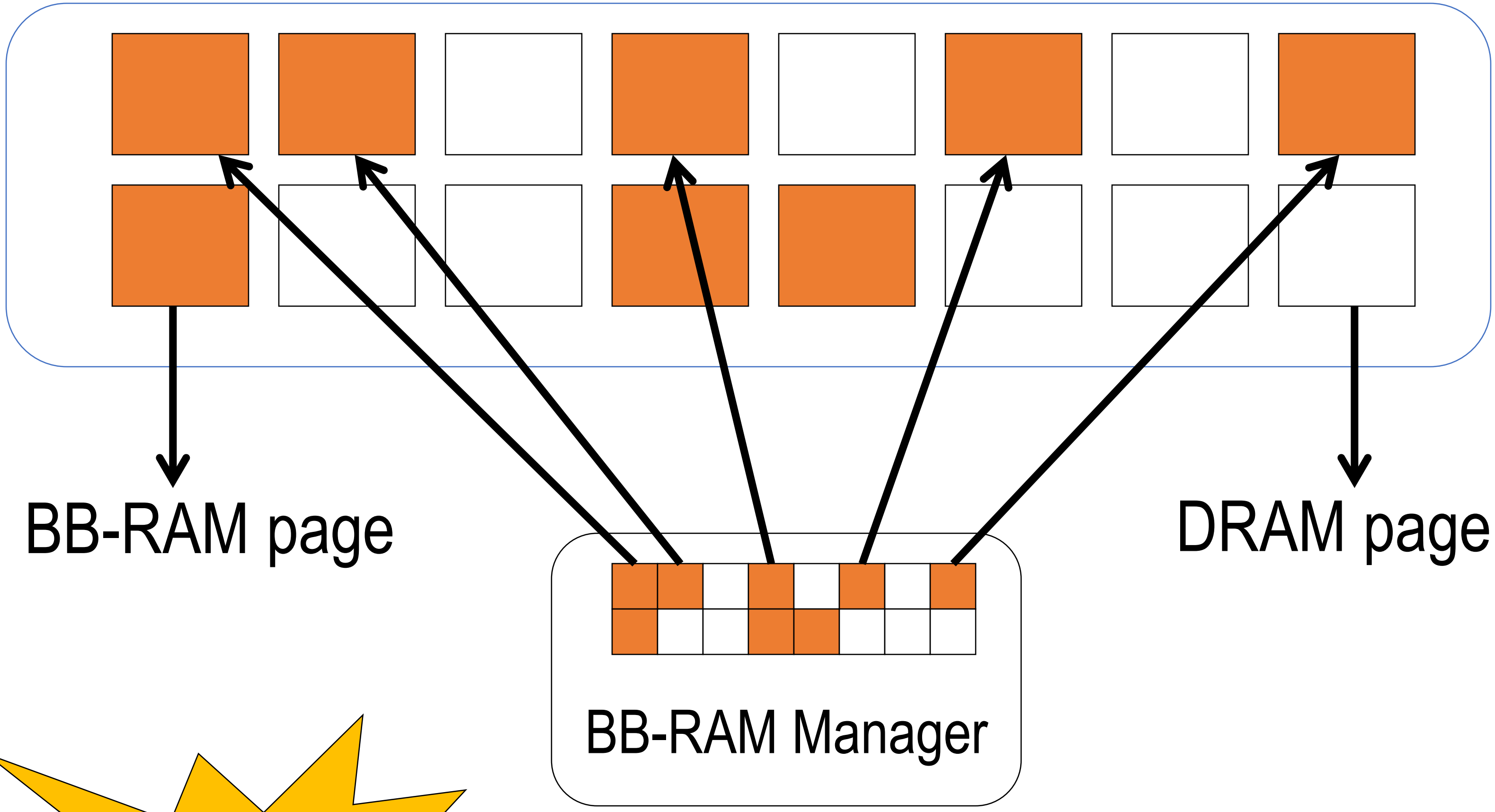
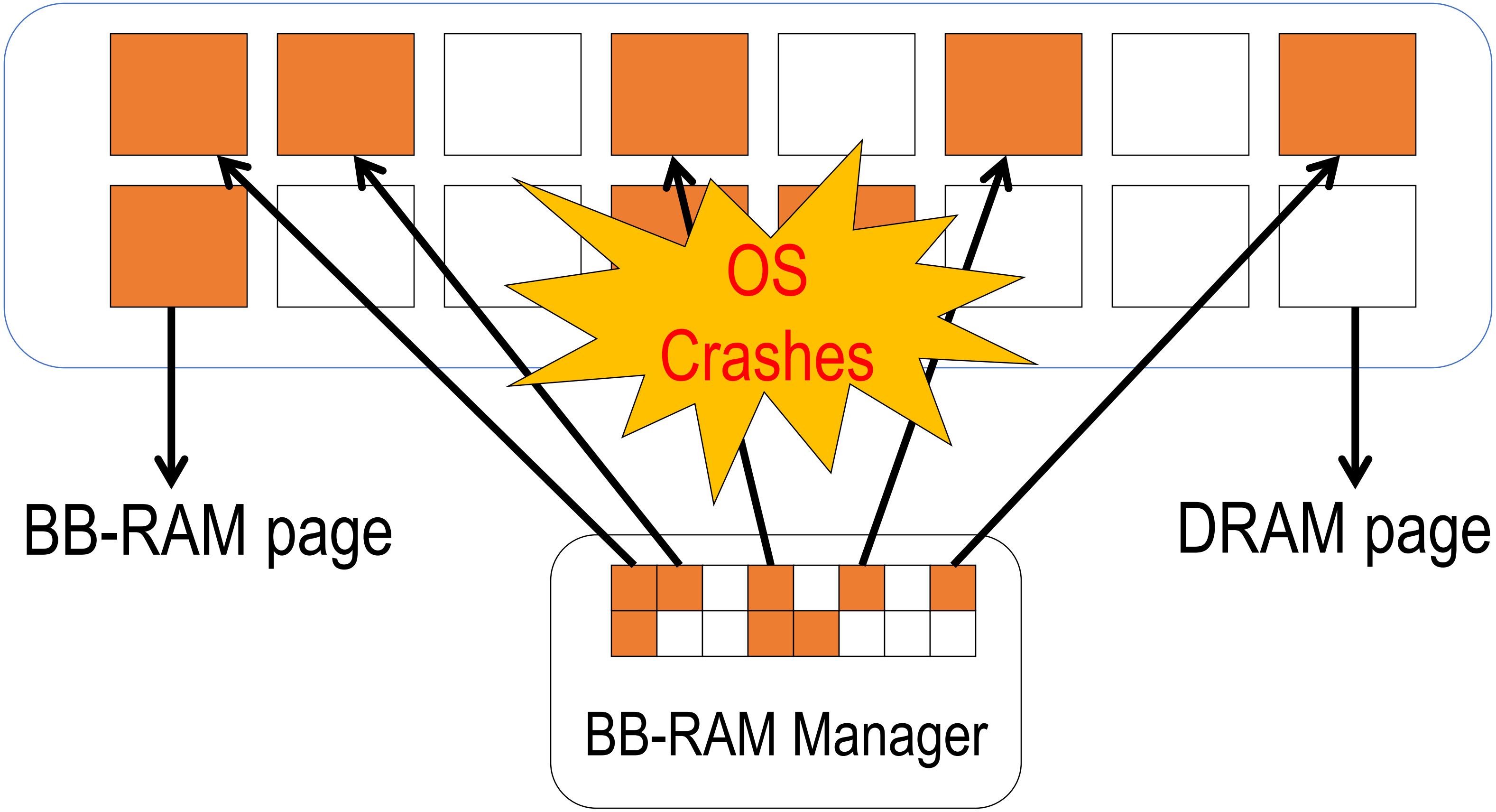


Automatically adjust BB-RAM size according to application requirement

Our BB-RAM Implementation



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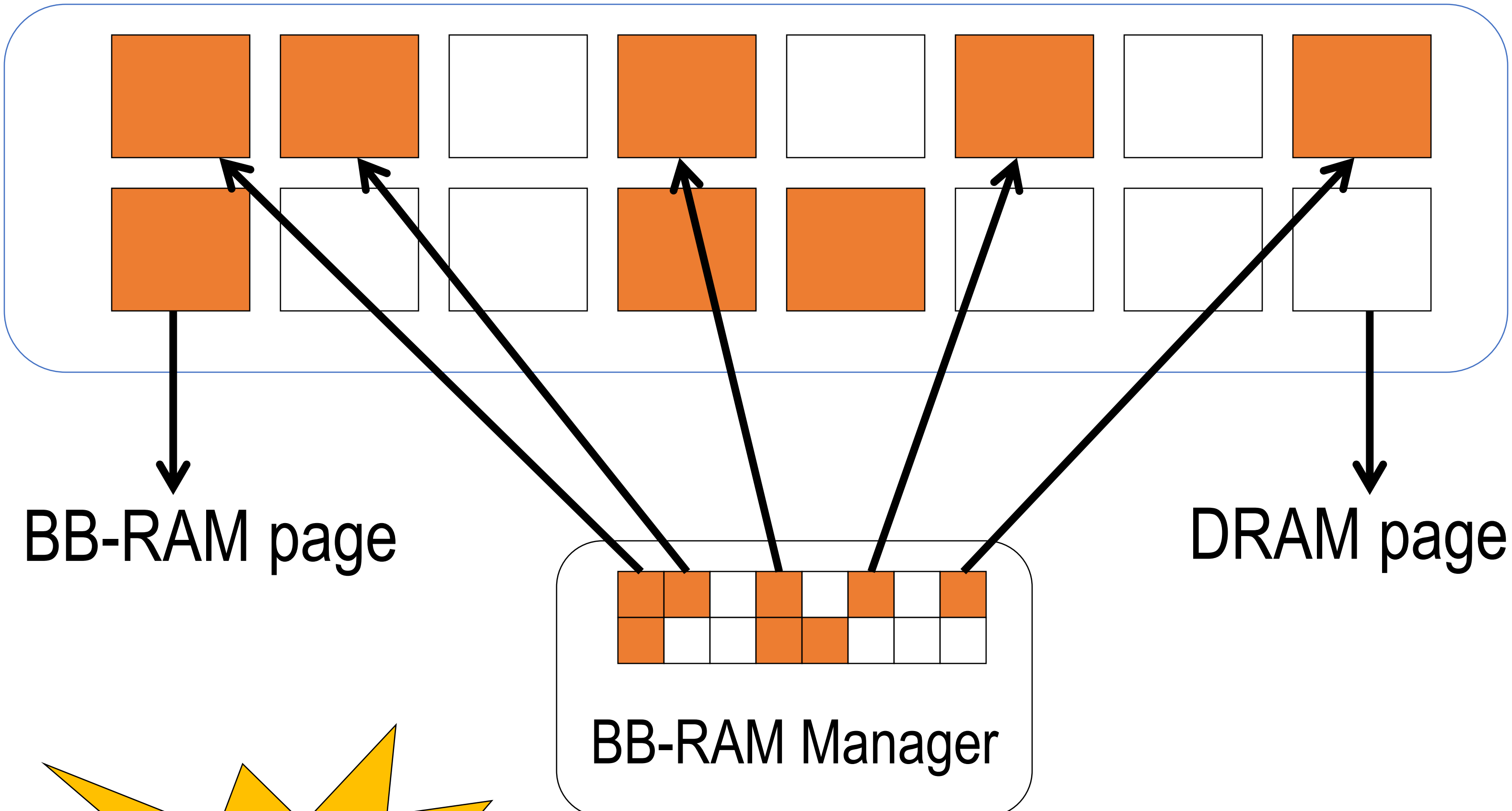

A watchdog timer to detect if OS is hung

Leveraging Phone for Capacity/Compute

Wearable applications focus on the latest data,

but how about the old data?

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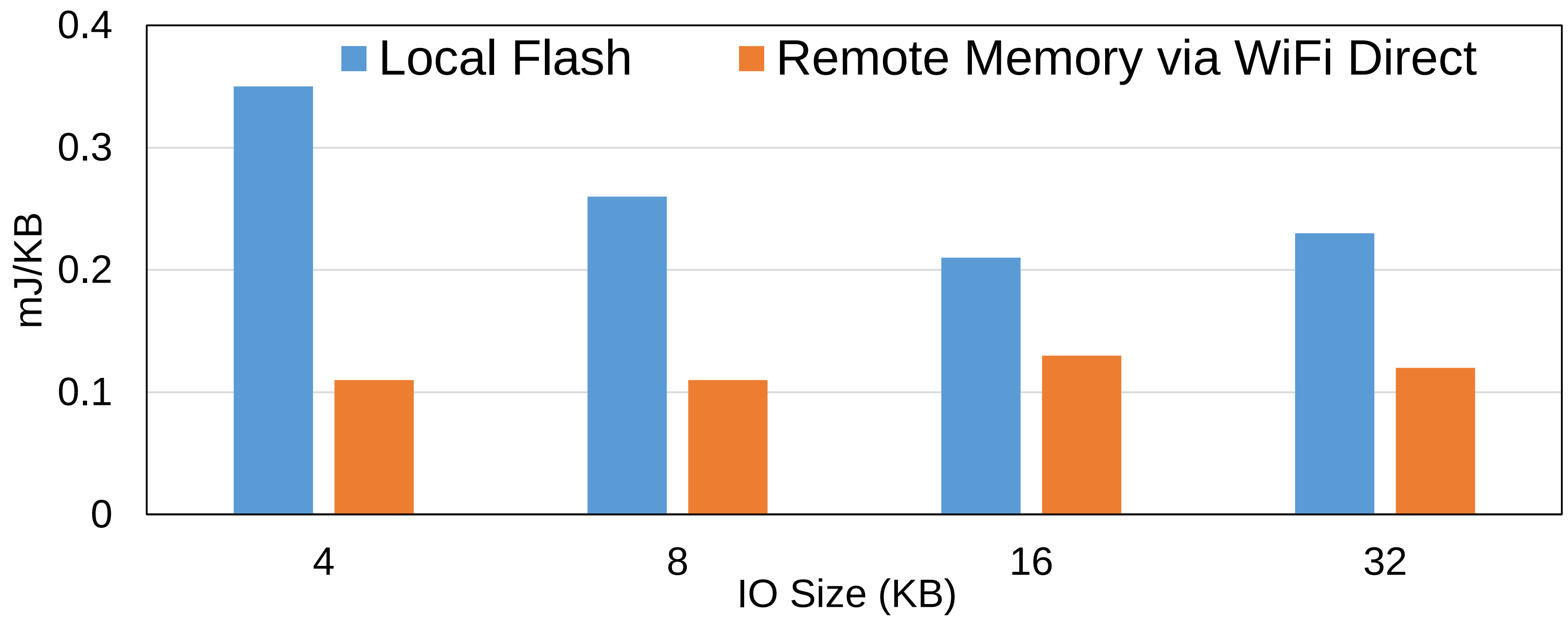

Two Moto E phones with 802.11 b/g/n

Writing data to remote memory via WFD is more energy efficient

Reaching the Phone Efficiently

	Standby Power	Data Transfer
BLE	Low	0.41 microjoules/bit
WFD	High	0.02 microjoules/bit

BLE for small data transfer, WFD for large data transfer

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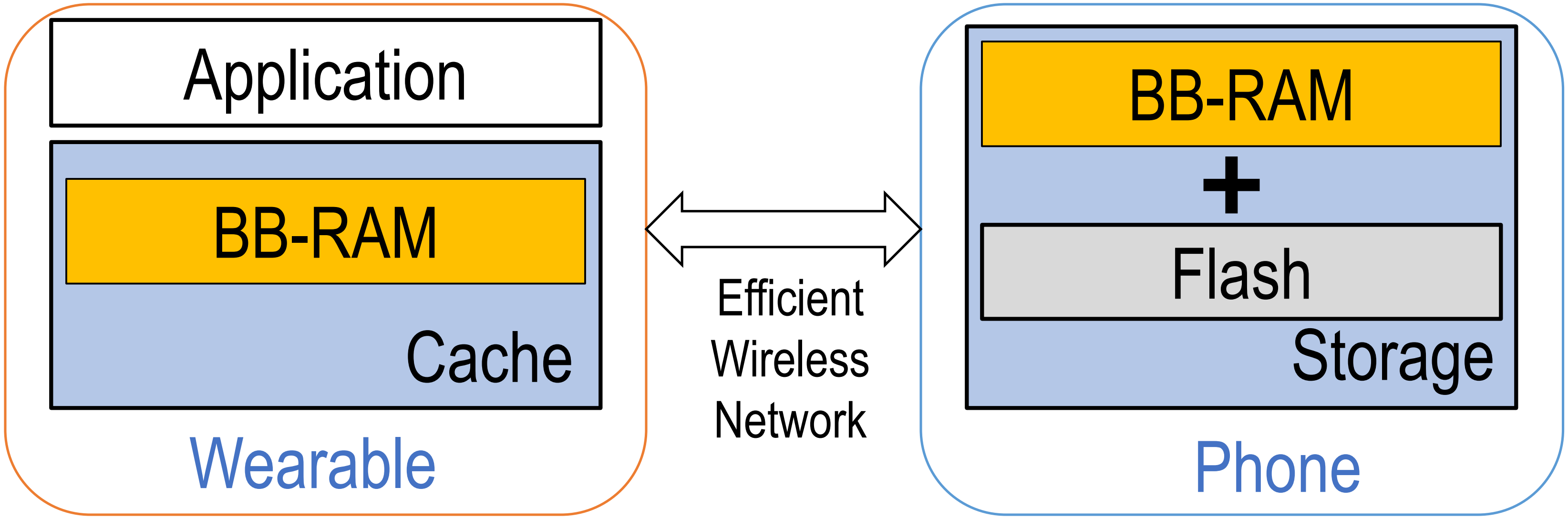
BLE for small data transfer, WFD for large data transfer

Use BLE's connection quality for reference

Building A Distributed In-Memory Storage System

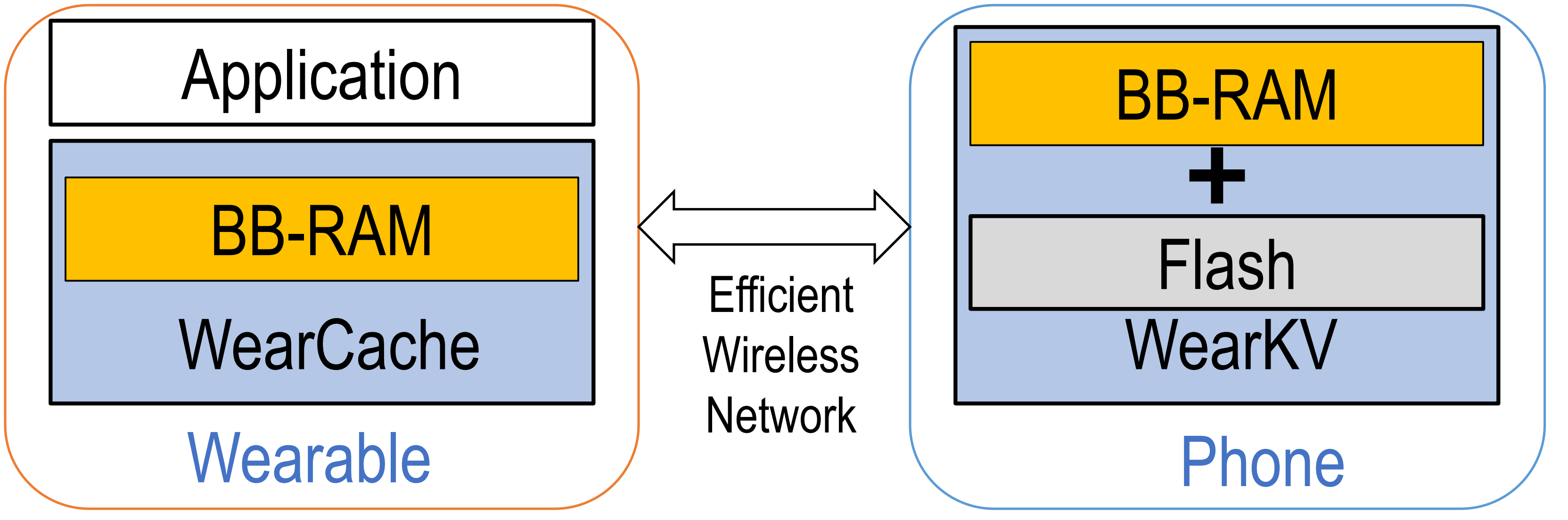


1 Improve performance & save energy

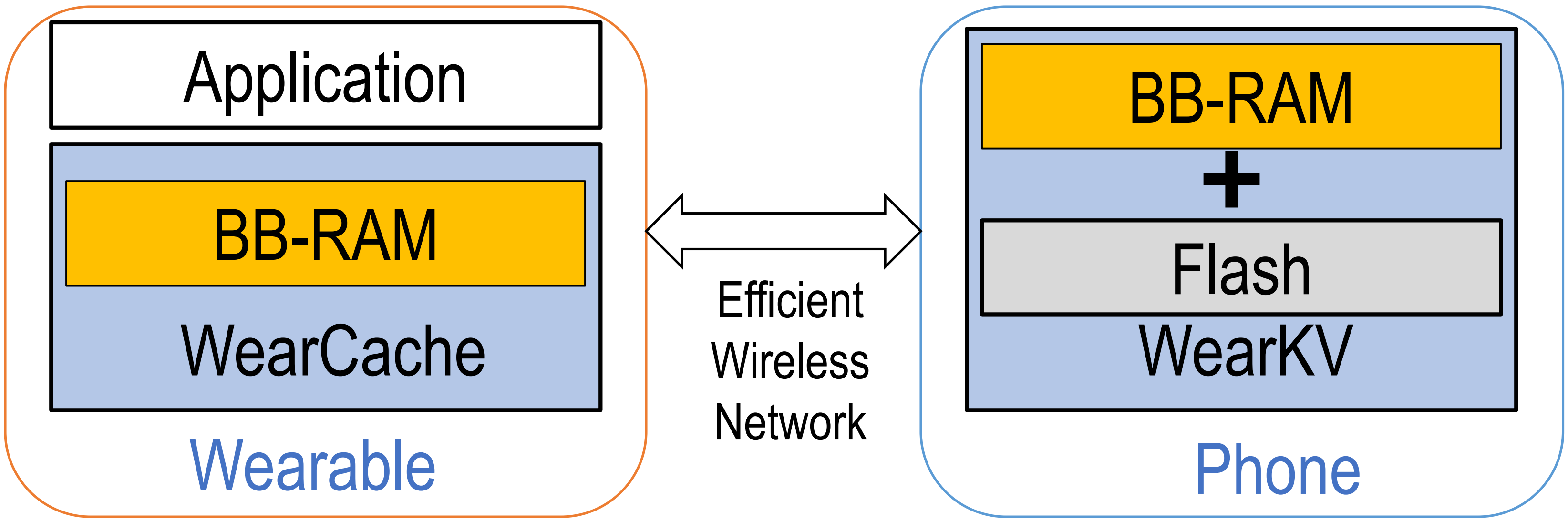
2 Reduce Flash size → reduce $ cost (10%)

3 Leverage phone's resources for wearable

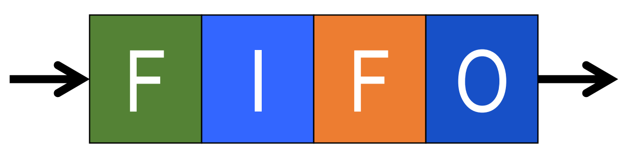
WearDrive Design: Key Value Store



WearDrive Design: Key Value Store



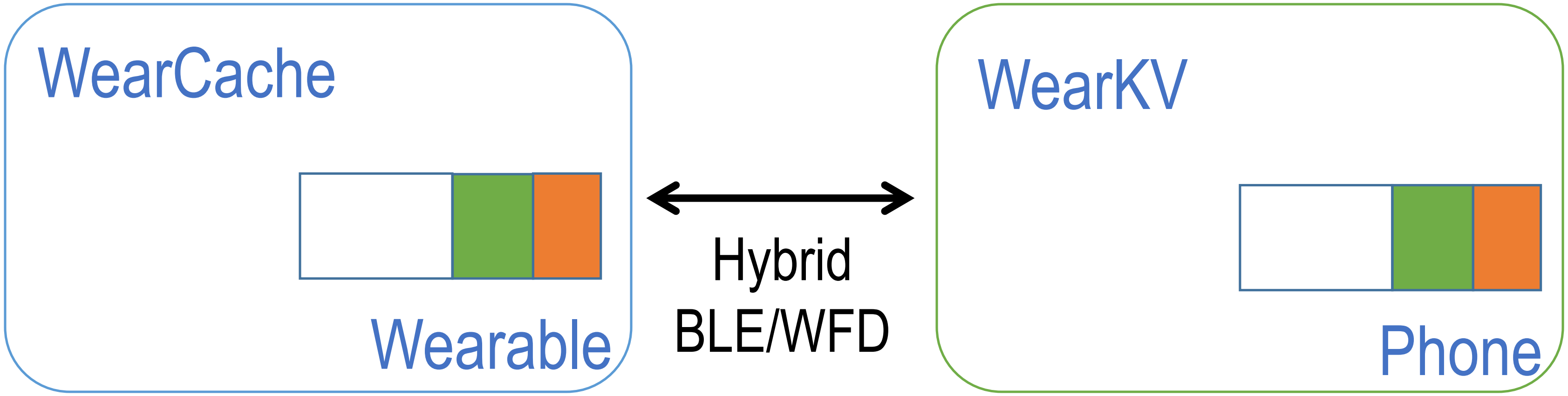
Why Key Value Store?



Focus on Latest Data

Hybrid Networks

Putting It All Together



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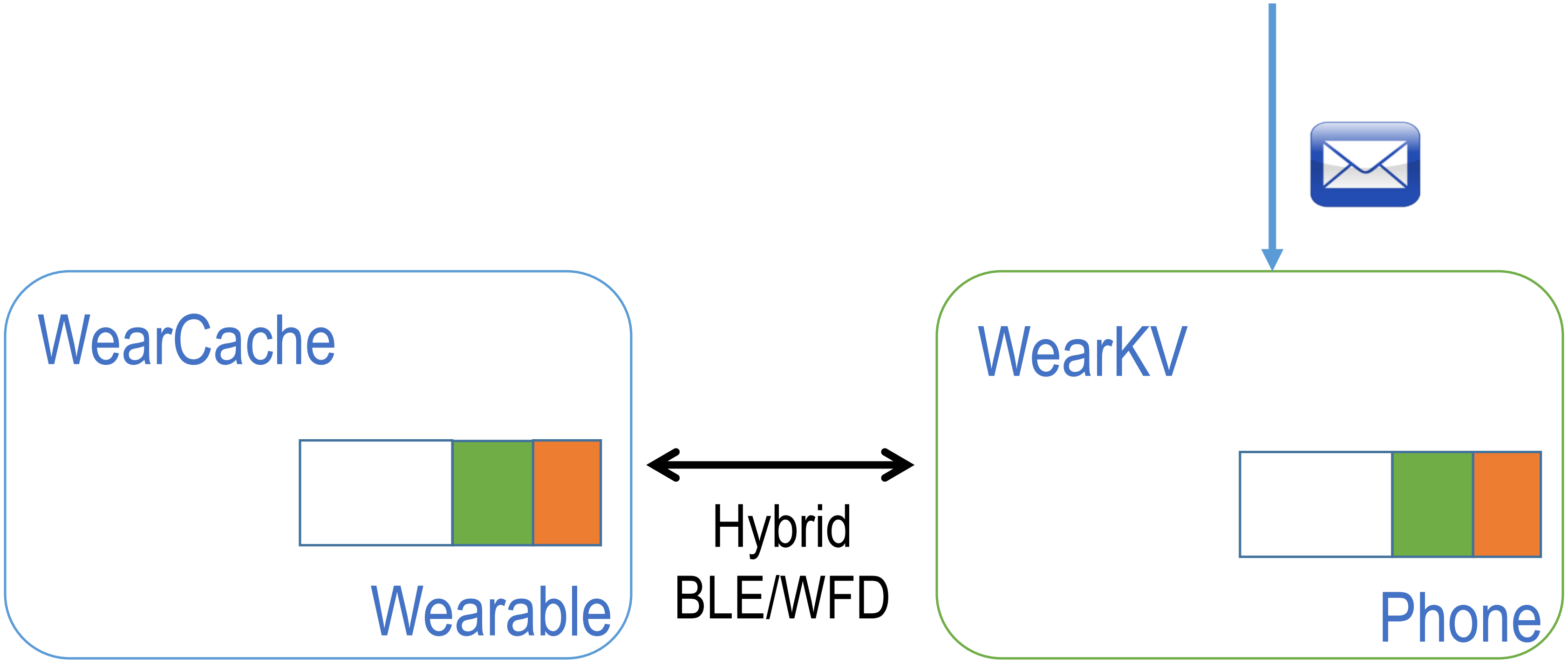

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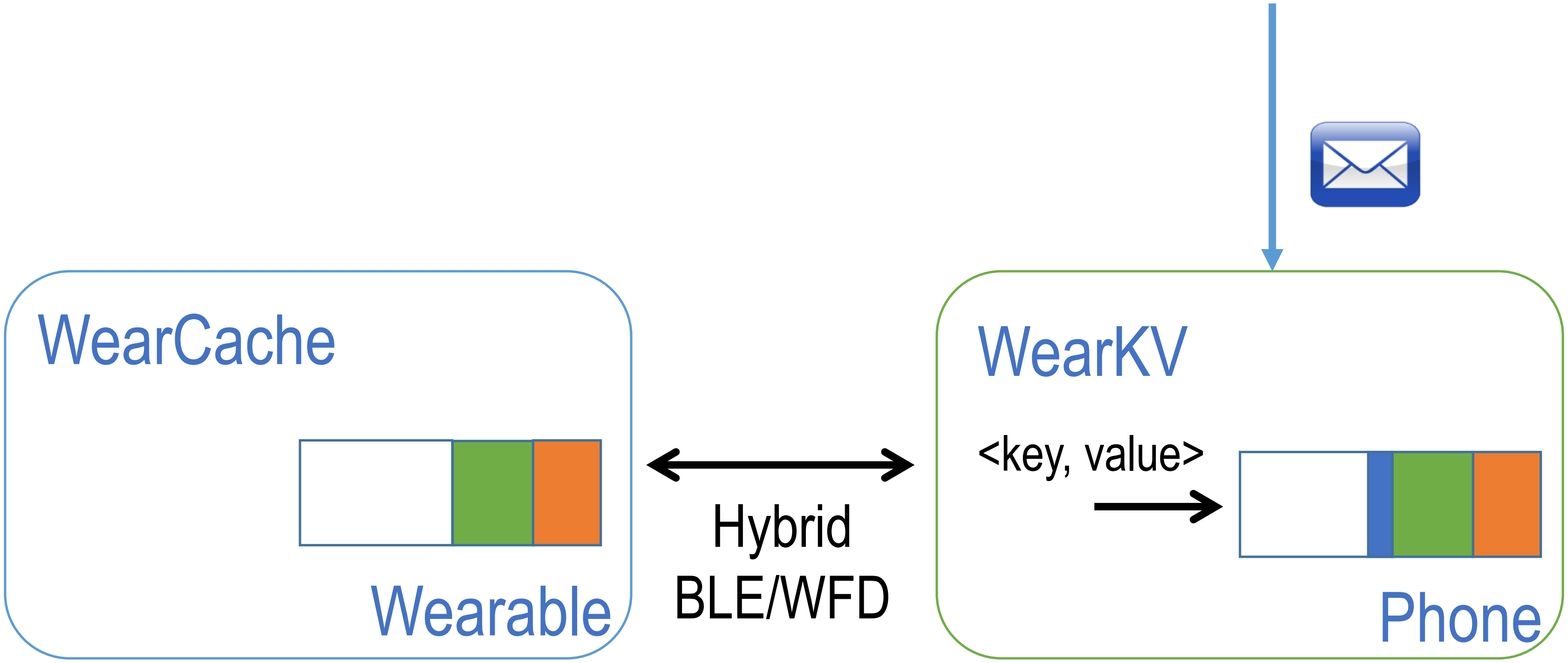

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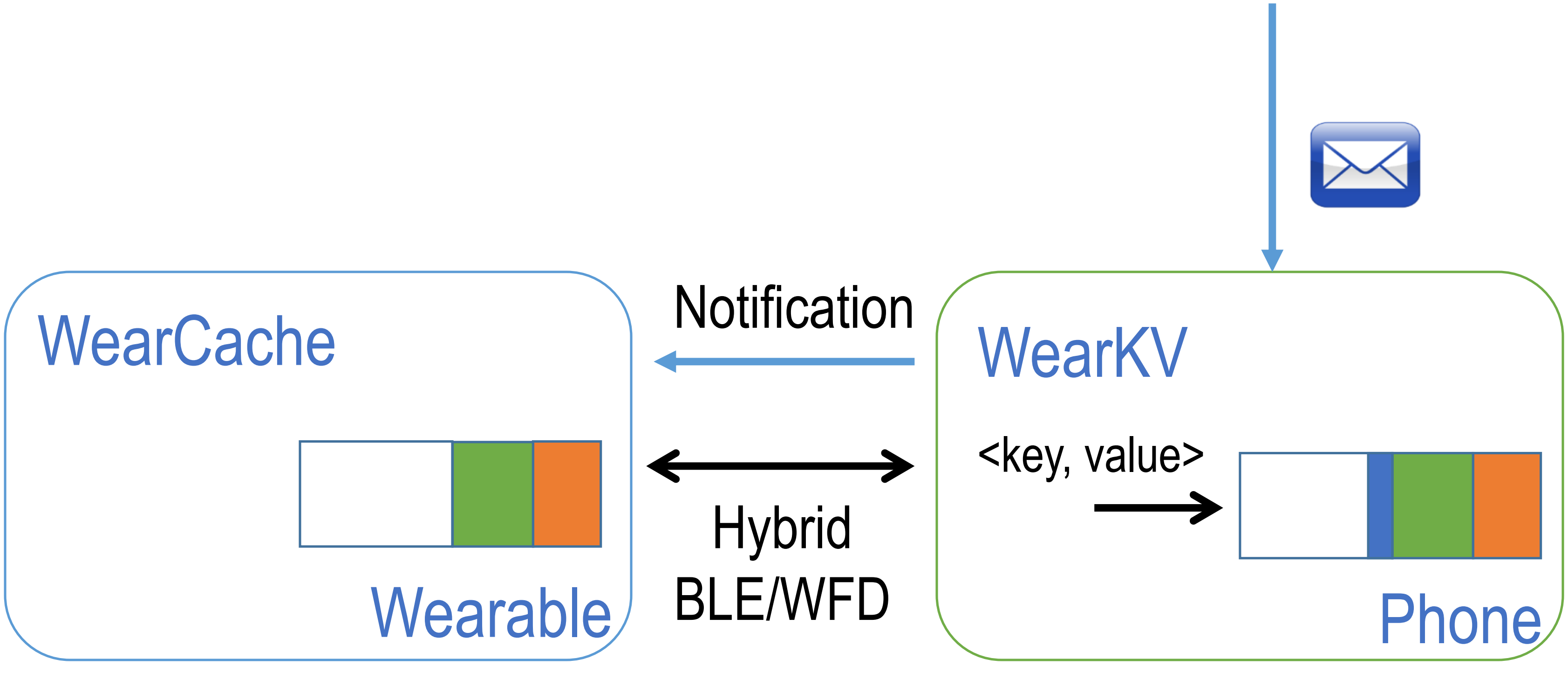

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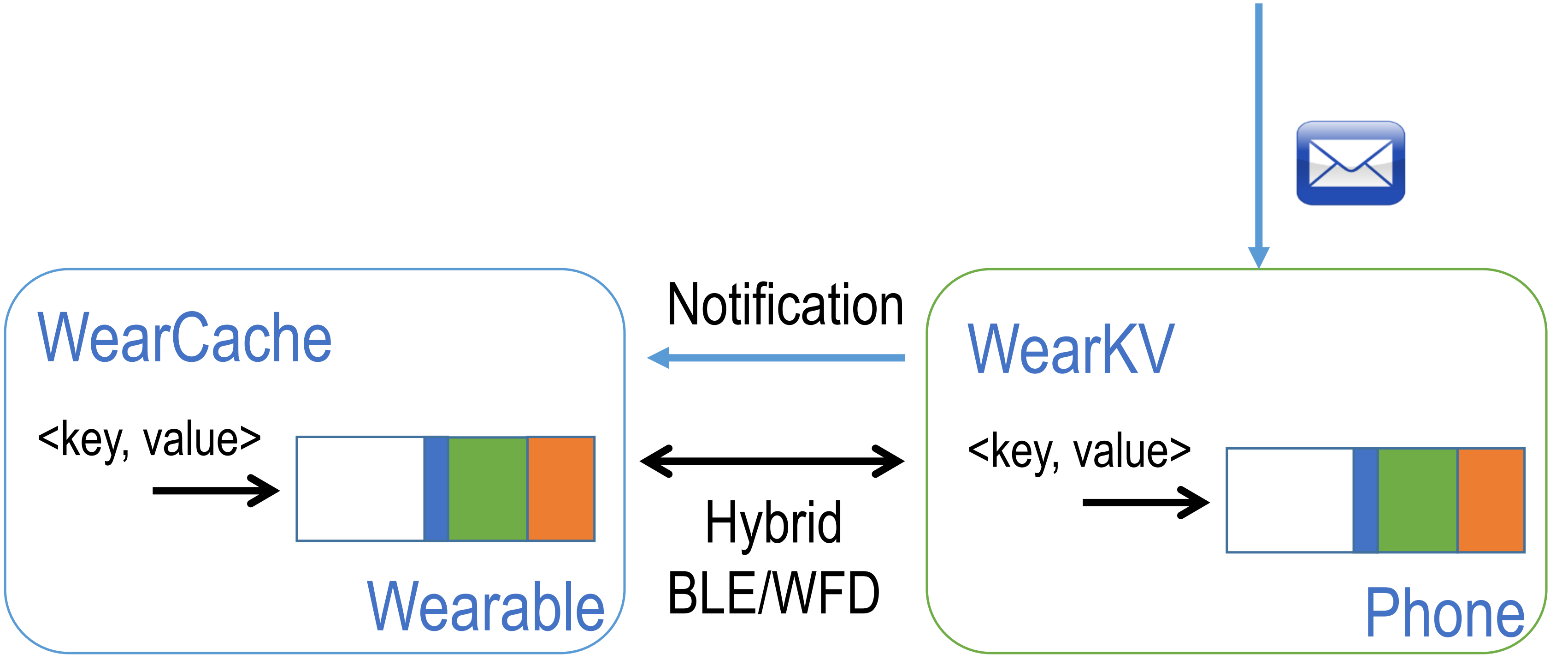

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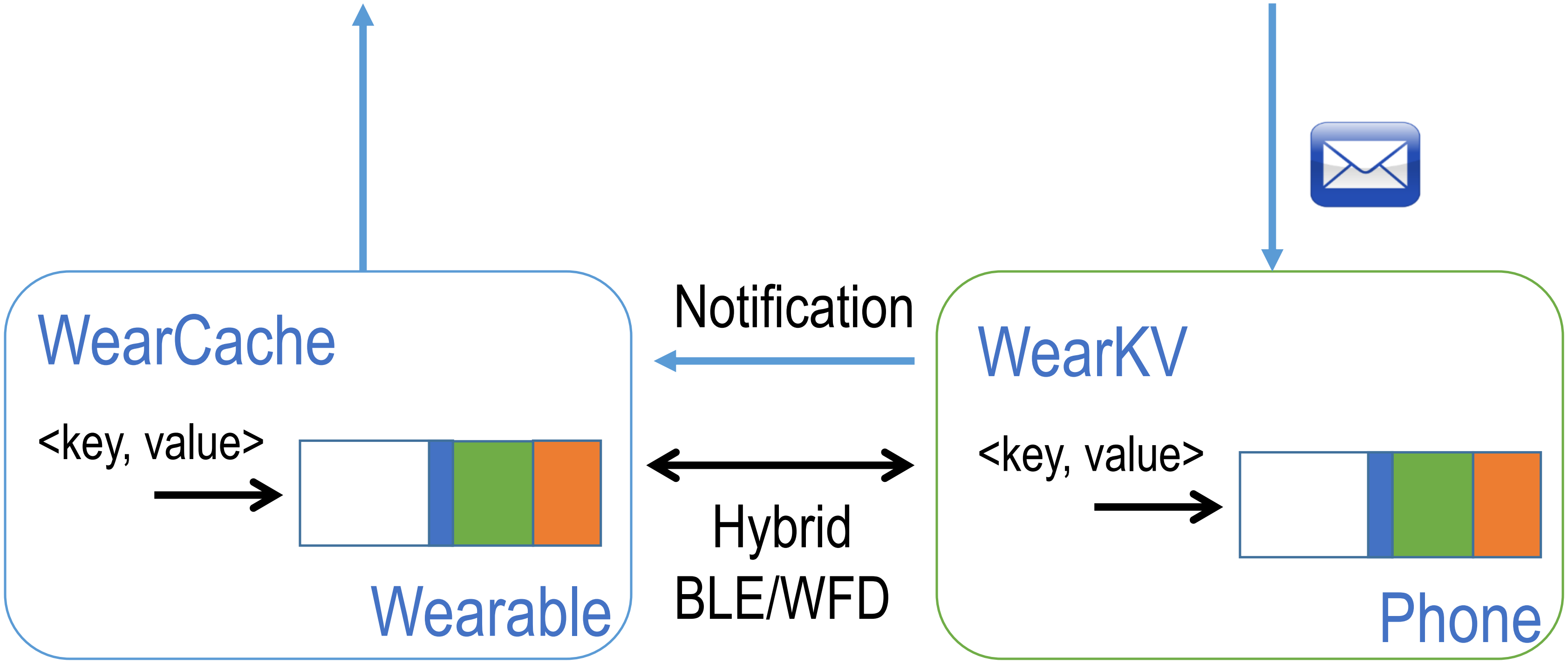

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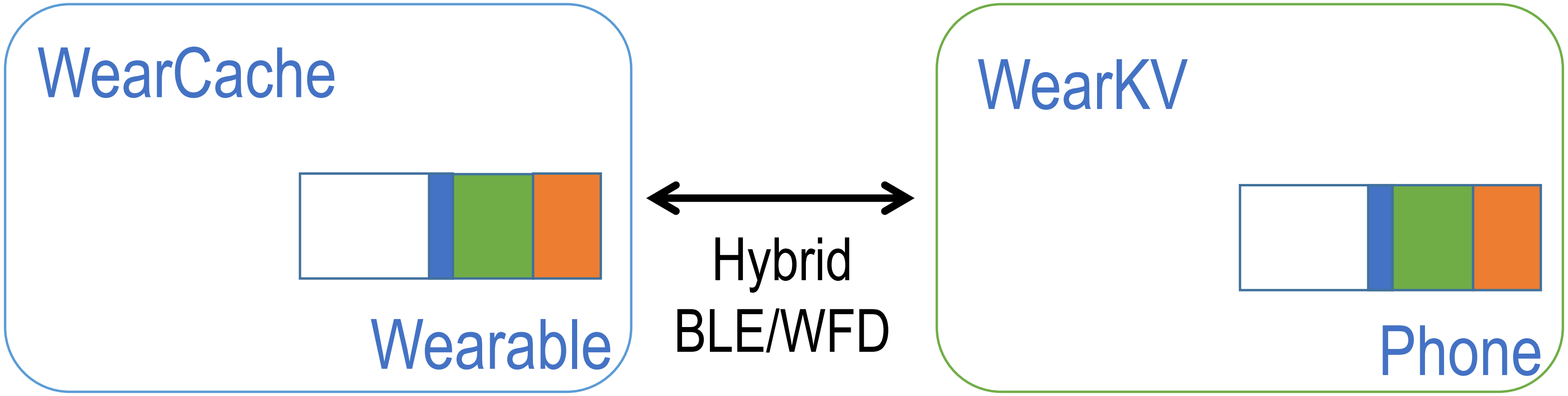

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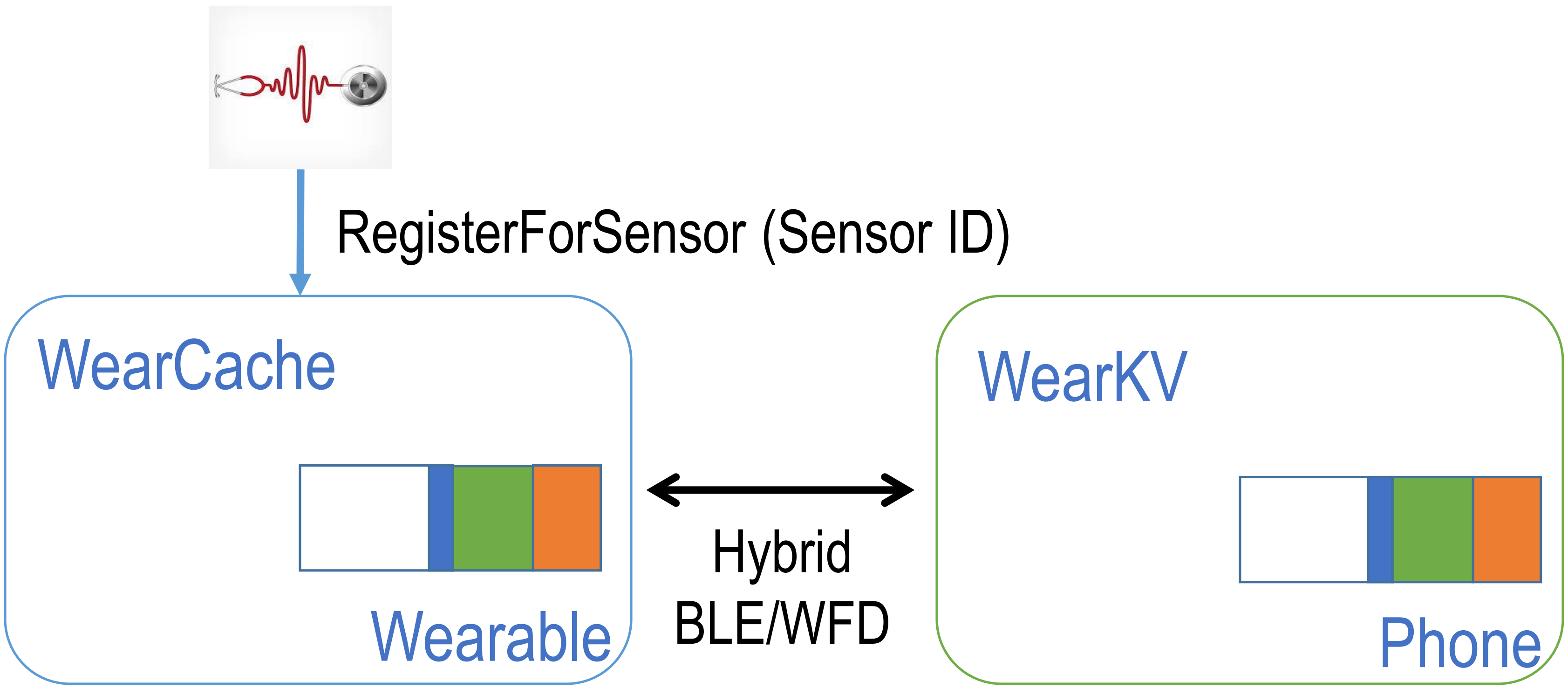

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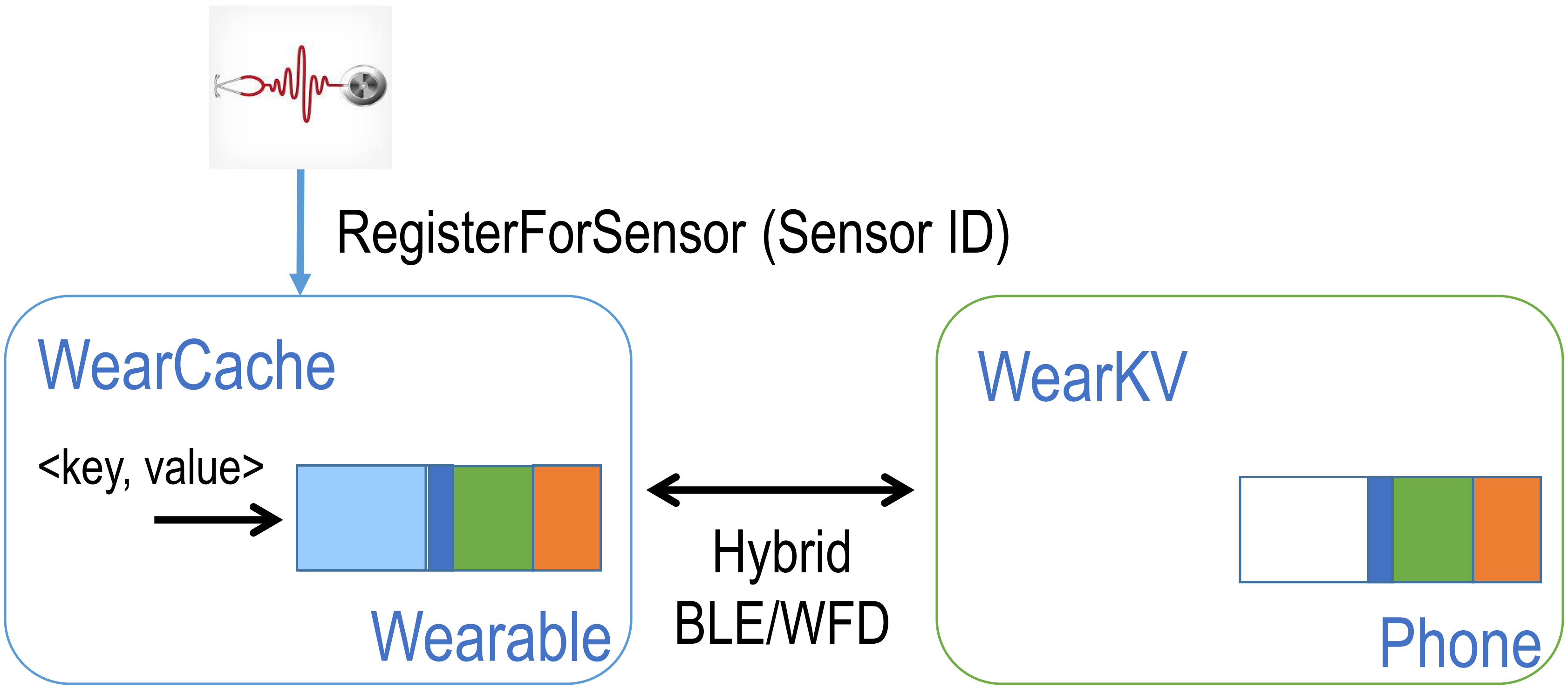

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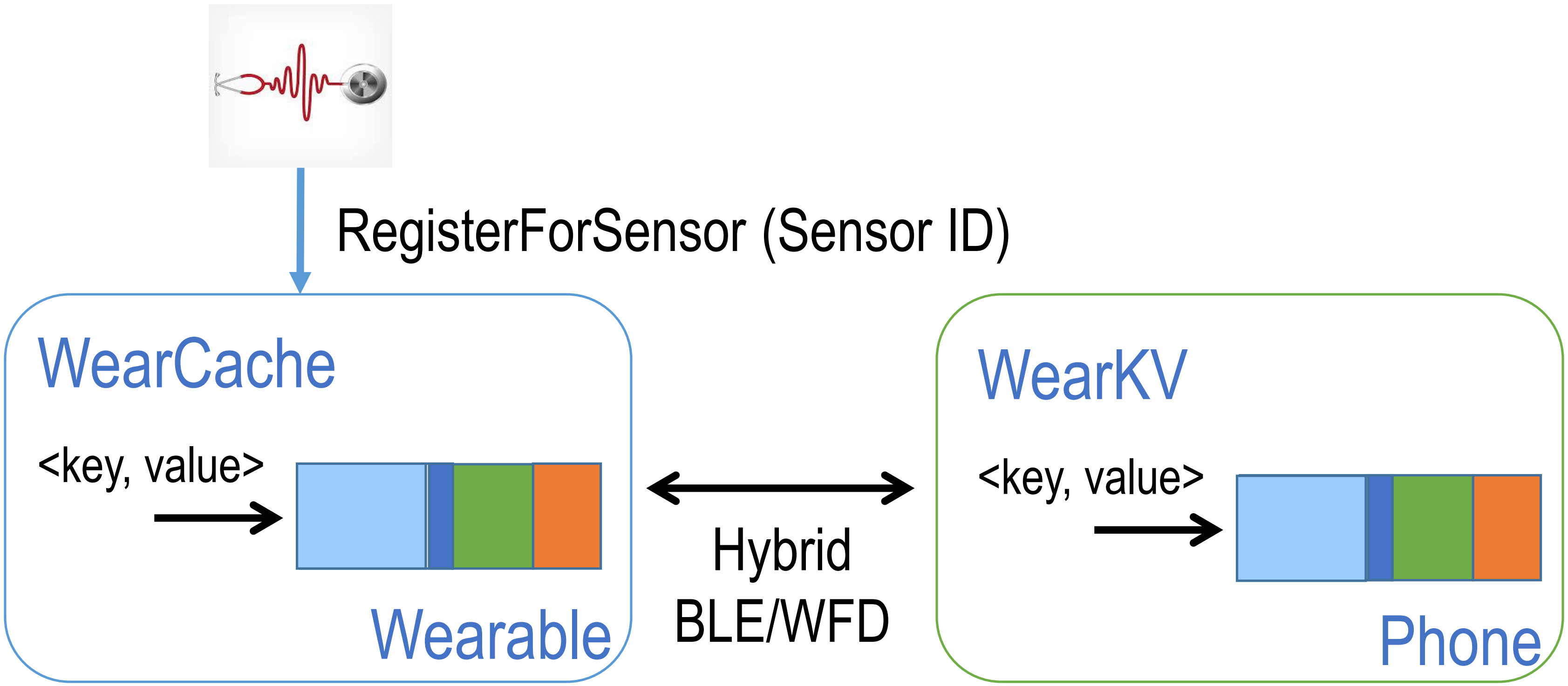

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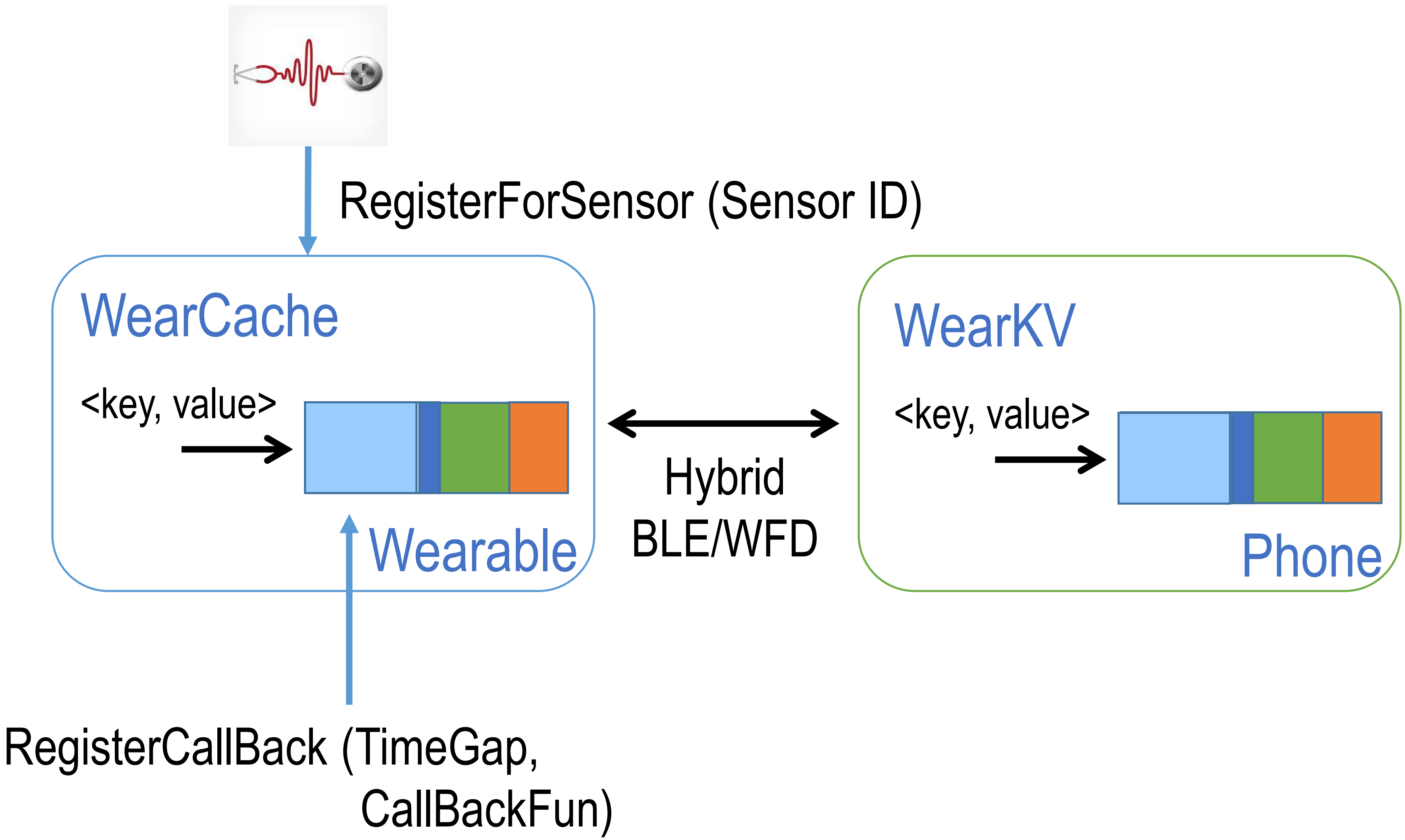

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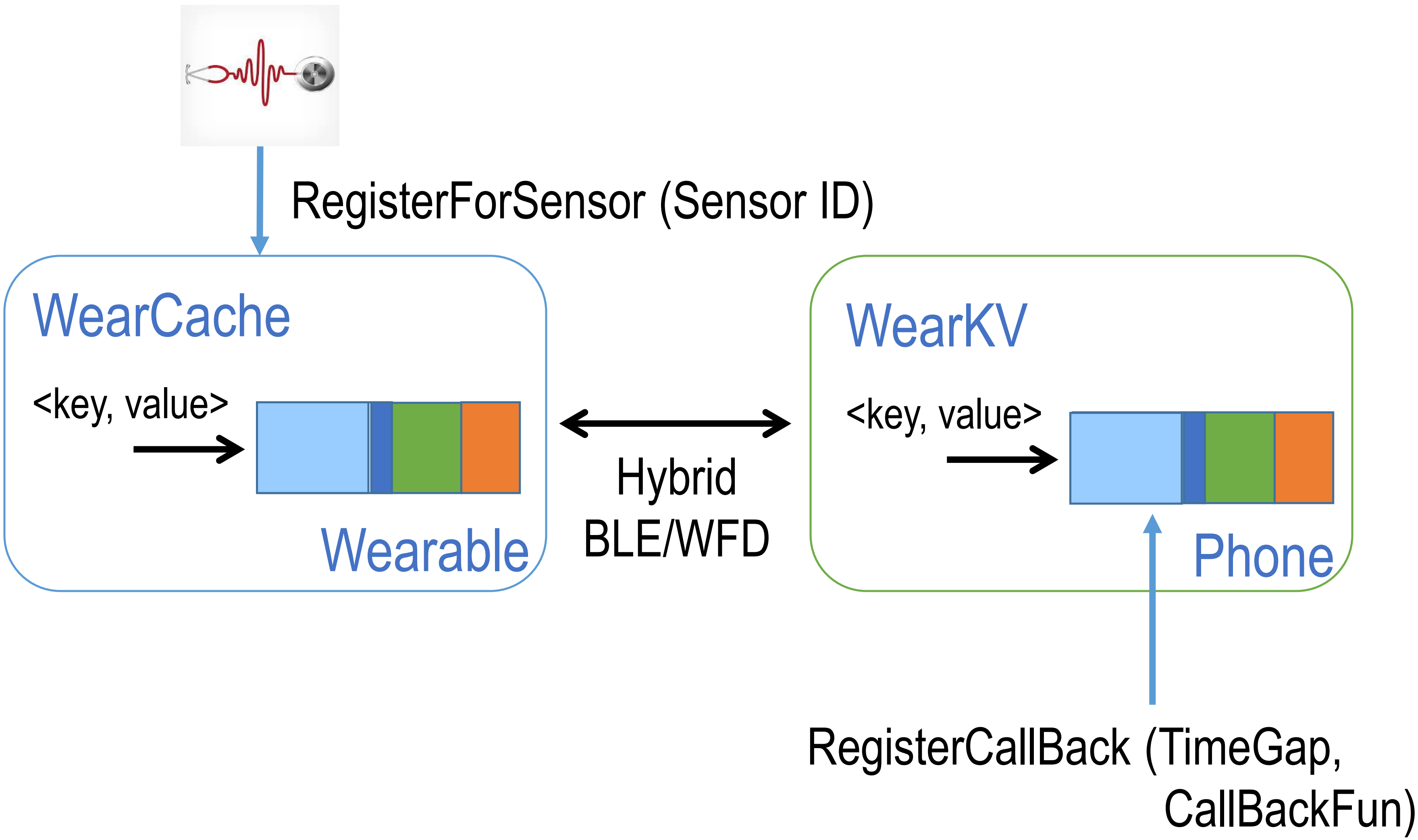

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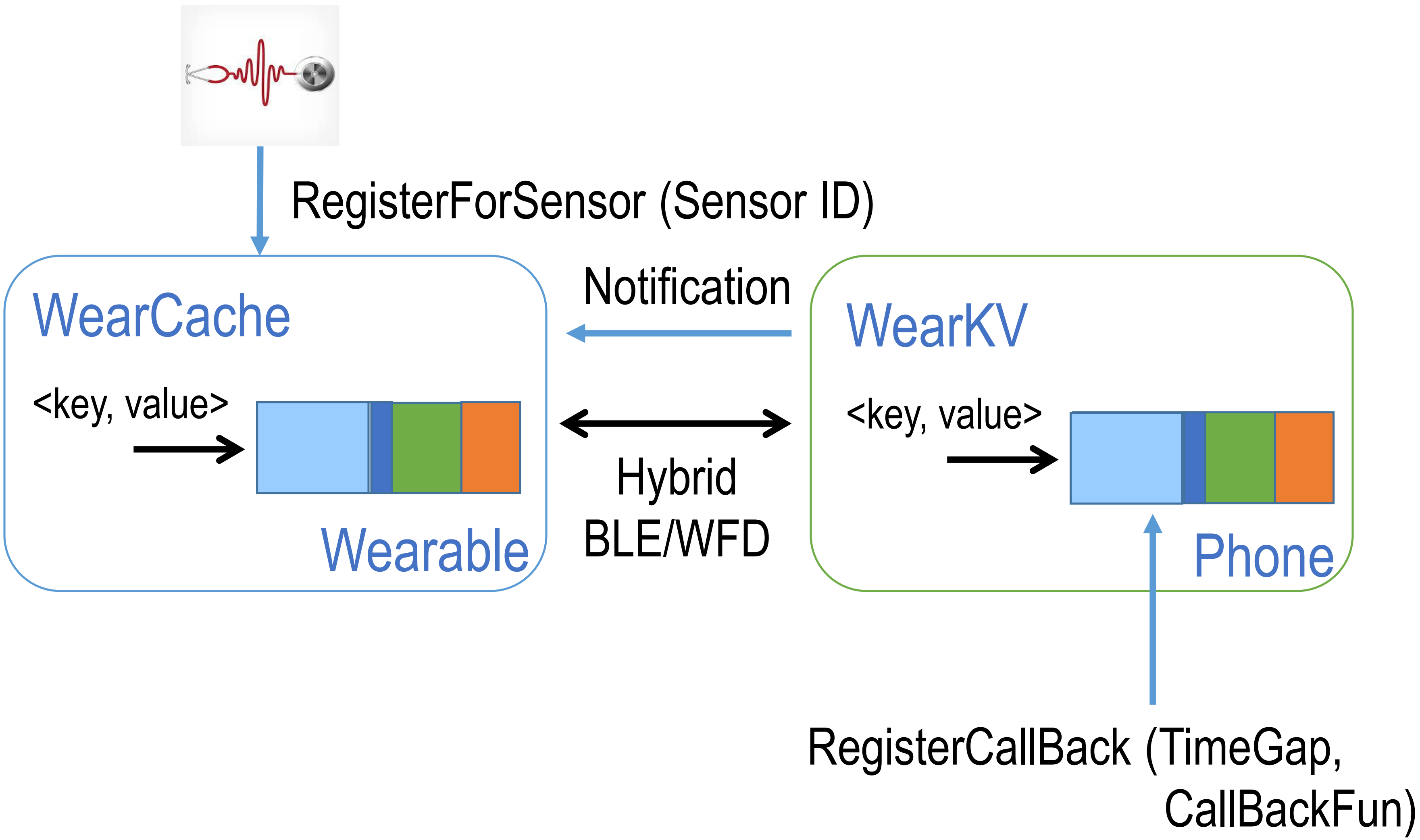
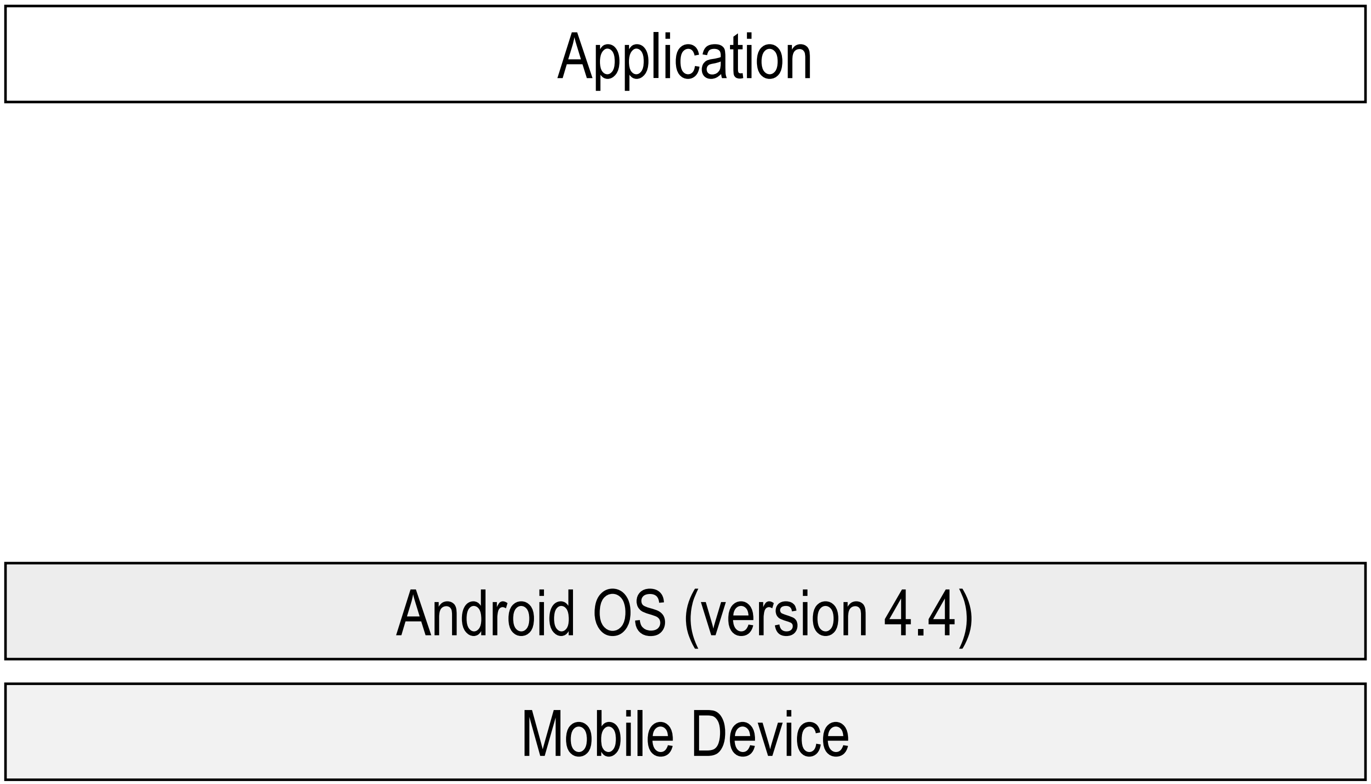


WearDrive: Implementation in Real System



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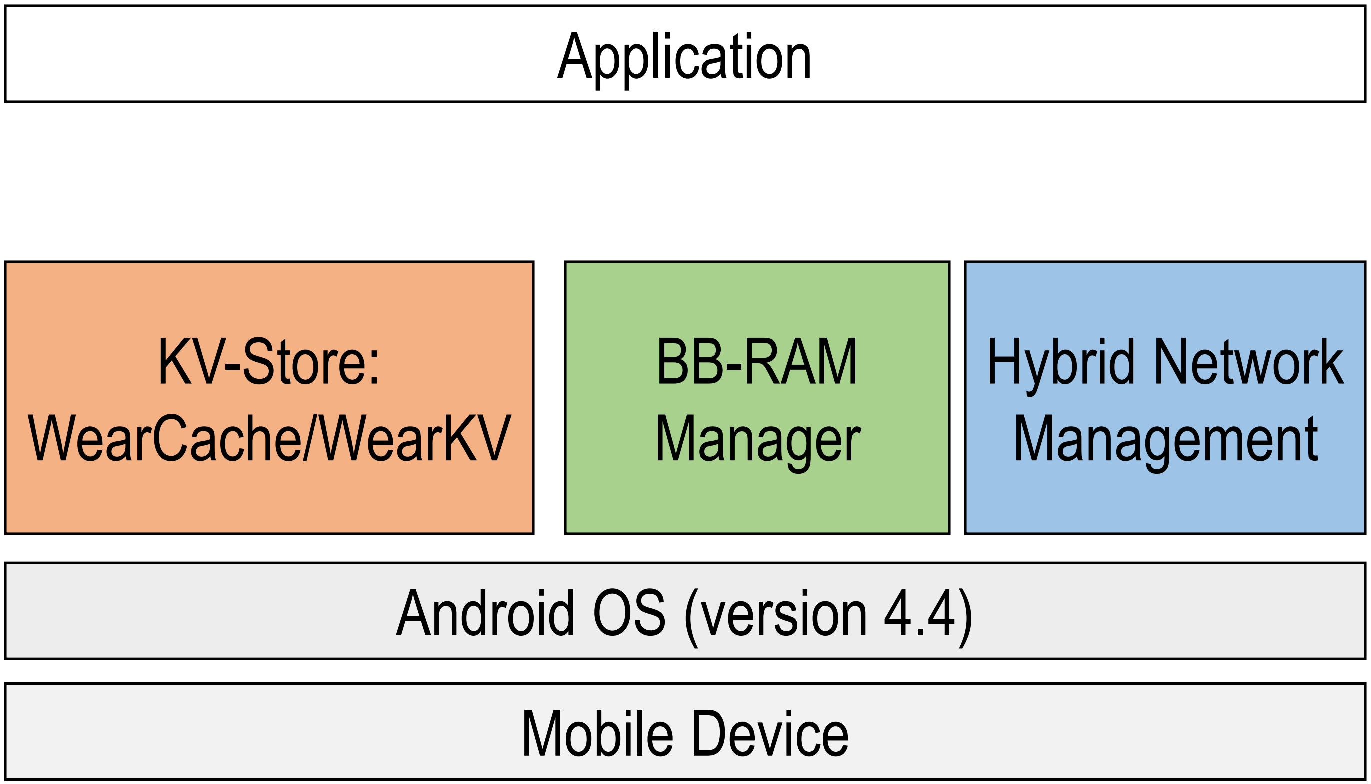

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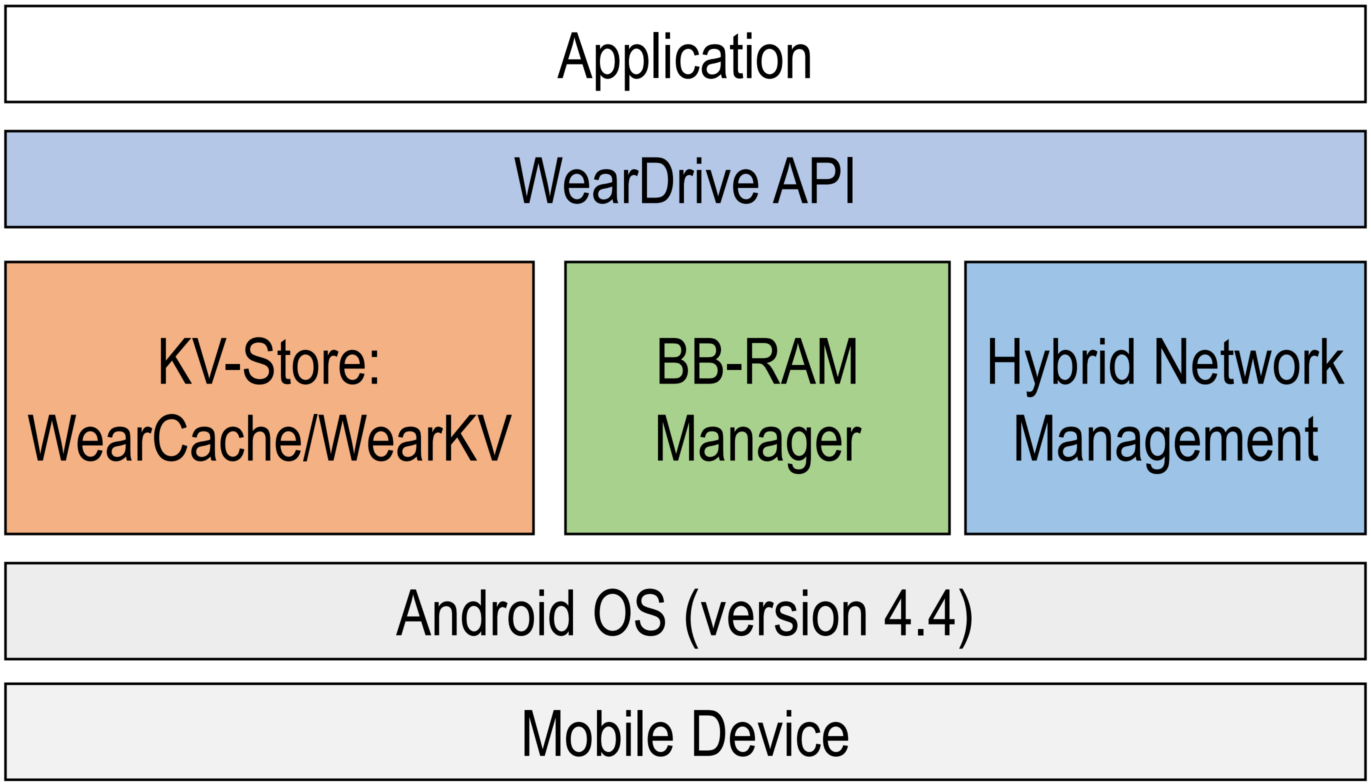


Experimental Setup

Emulated wearable device (similar to Samsung Gear)

1.2 GHz Dual-core + 512 MB RAM + BLE 4.0 + WiFi 802.11 b/g/n

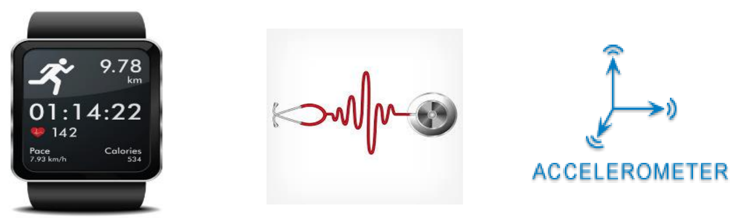
Monsoon power monitor

Experimental Setup

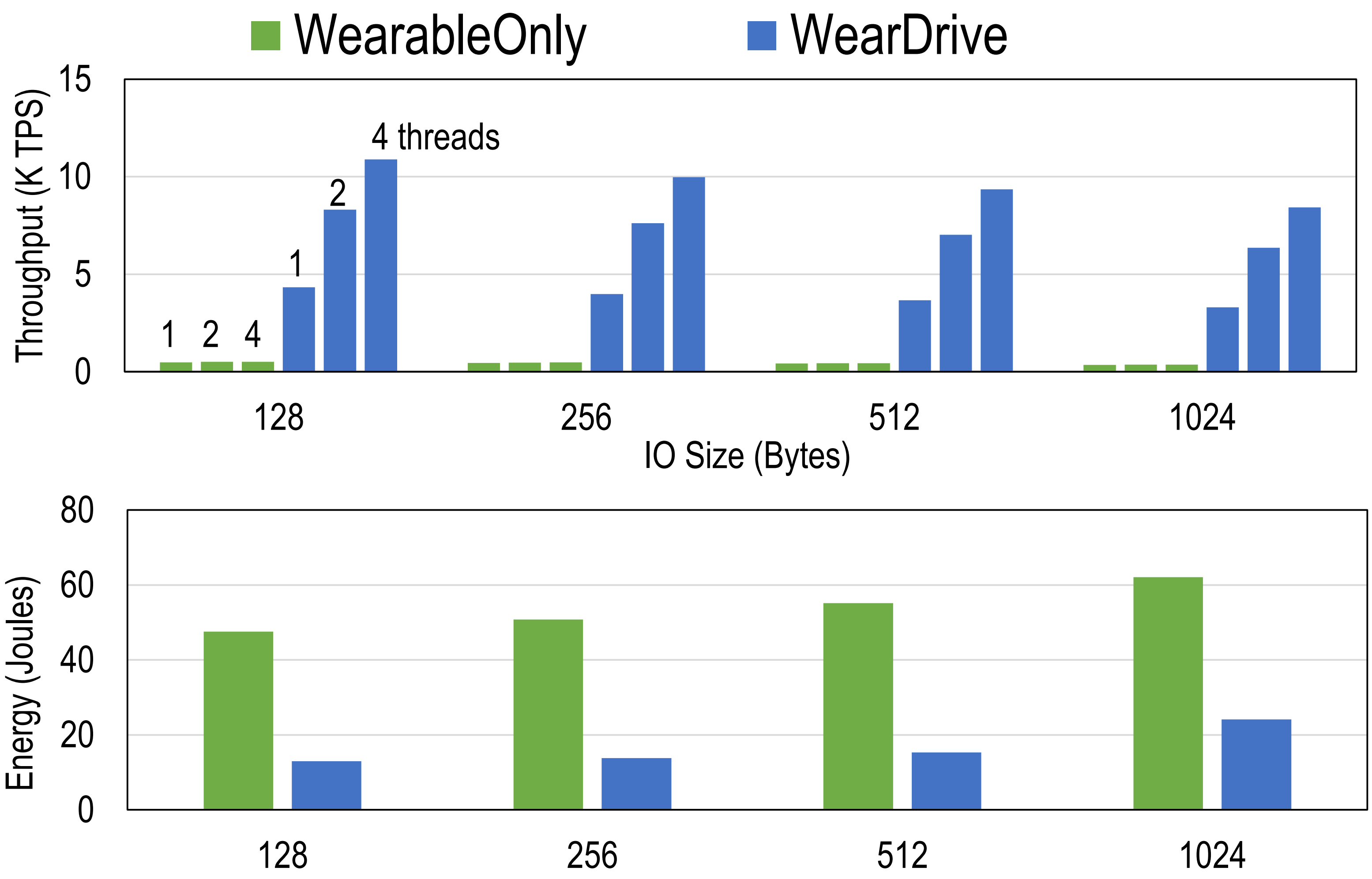
WearableOnly	Use local Flash as storage
WearSDK★	Android Wear SDK
WearDrive	In-memory storage system

★we extend its data layer to make it support WFD and hybrid network protocol.

WearBench: Benchmarks for Wearables

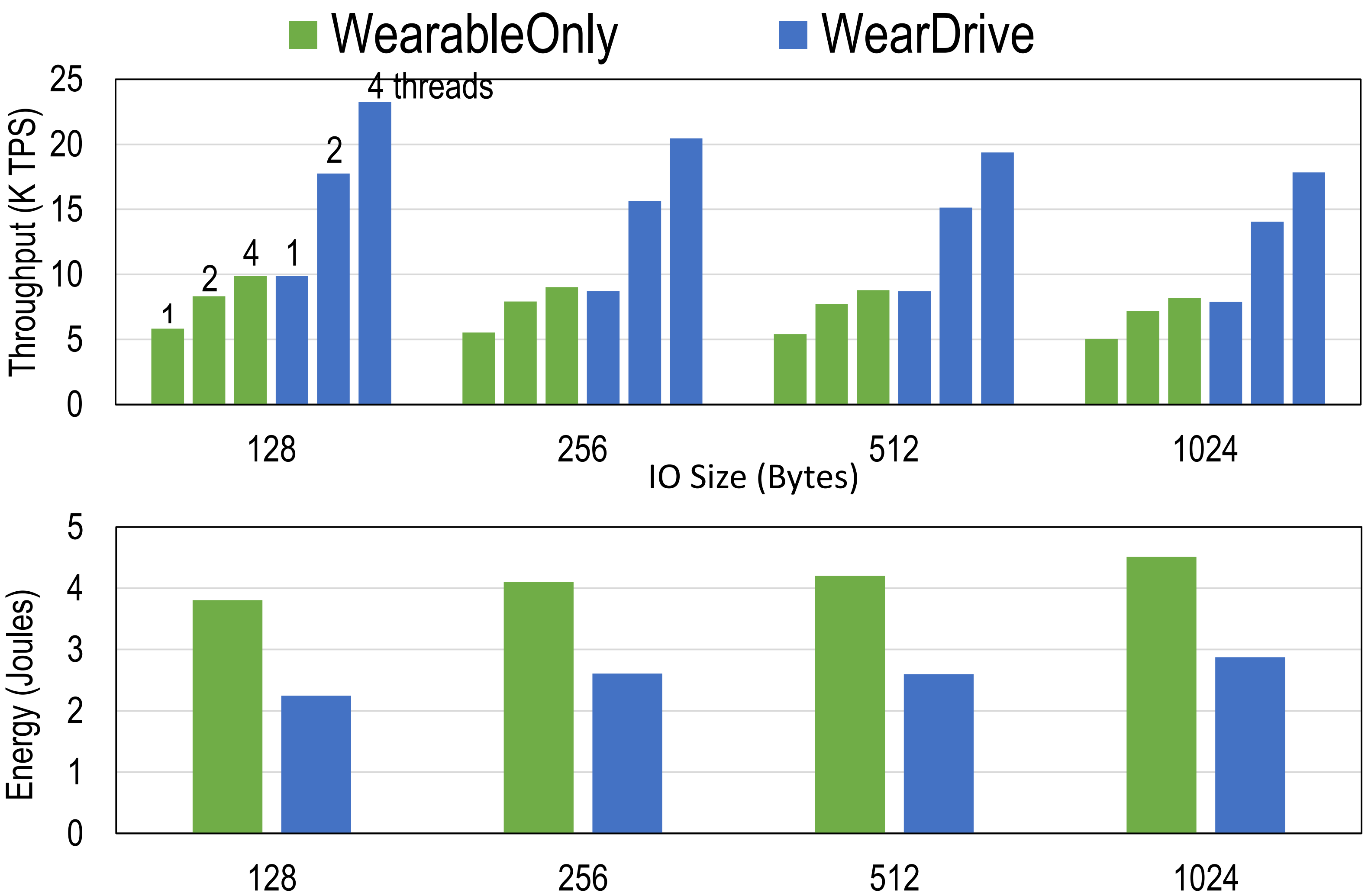
	Examples	Parameters
Extended Display		Size, inter-arrival time
Sensors		Sampling rate, monitoring period
Audio/Video		Encoding rate, quality, monitoring period

Local Memory vs. Local Flash (Write)



9x performance improvement, 4x less power

Local Memory vs. Local Flash (Read)



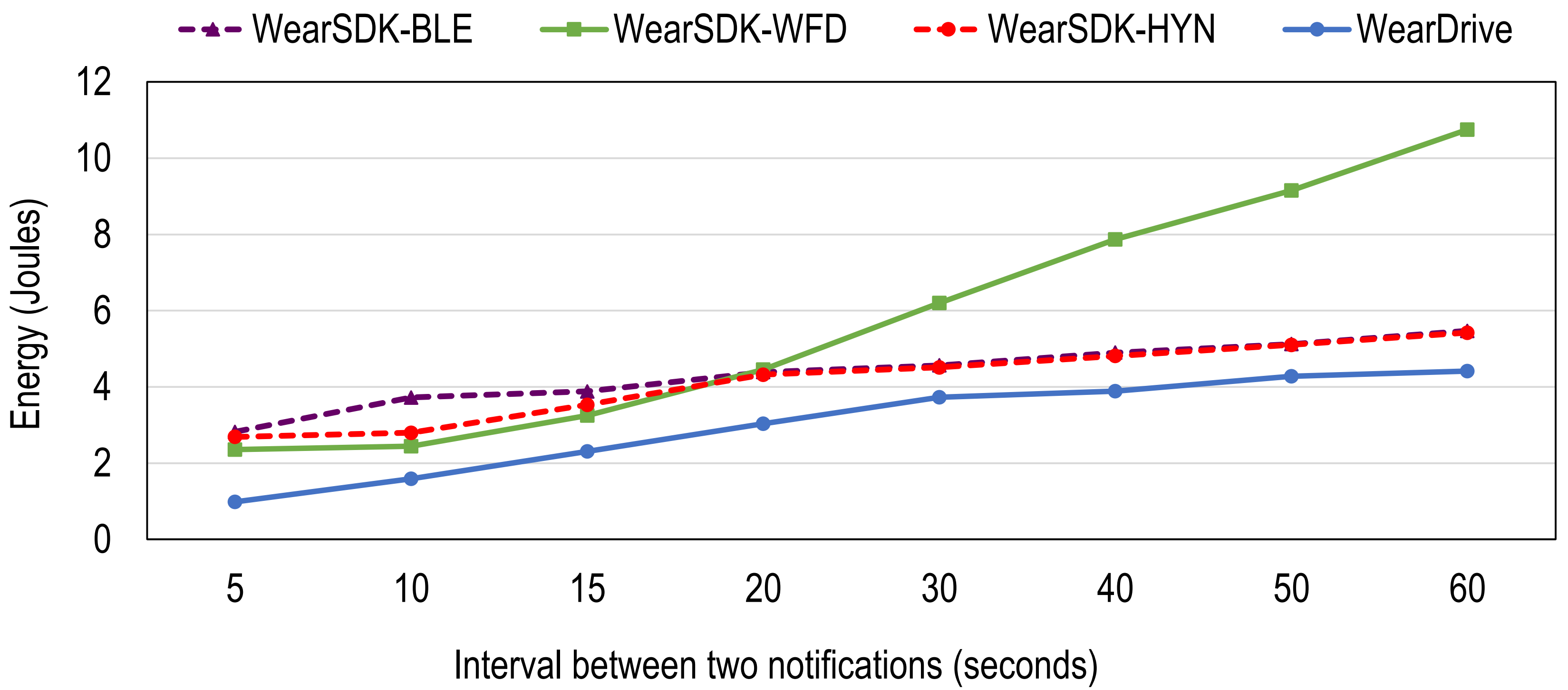
2x performance improvement, 1.7x less power

Energy Usage of Sensor Data Aggregation

The sensor samples values continuously at 1 Hz for 24 hours

WearDrive consumes 1.5x less power than WearableOnly, up to 3x less power than WearSDK

Energy Usage of Receiving Notifications



WearDrive saves 1.2 - 3x energy than WearSDK-BLE

Compute Offload & Impact on the Phone

	Wearable (300 mAh)	Phone (2000 mAh)
WearableOnly	27.12%	--
WearableOnly +InMemory	13.23%	--
WearDrive	0.87%	2.09%

Data analysis with k-means on the data set generated by 16 sensors at 1 Hz for 24 hours.

Conclusion

WearDrive: Storage System for Wearables

1 **In-memory Storage System**
with battery-back DRAM (BB-RAM)

2 **Extended Capabilities**
leveraging phone's storage and CPU

3 **Extended Lifetime**
3x improvement on battery life time

Thanks!

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Q&A