User-driven in-network computing at the (IoT) edge

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Context

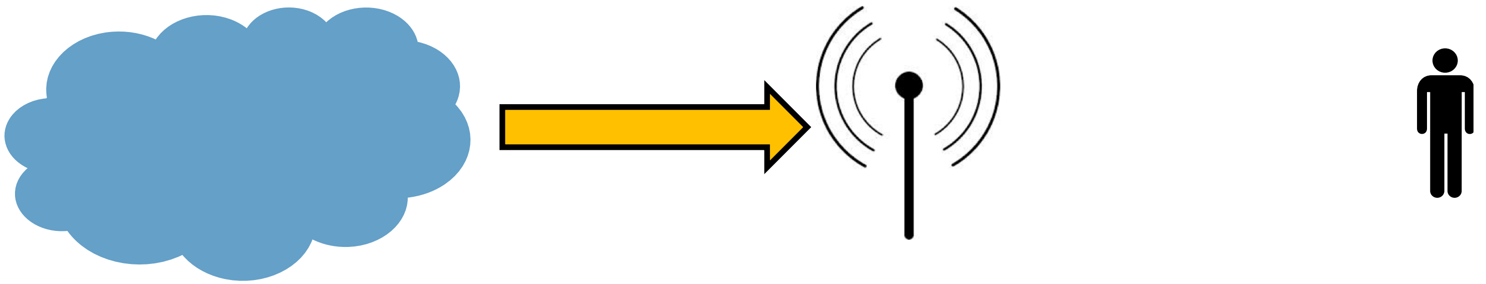
- Internet of Things
  - Specific device capacities rather than just generic compute power
  - Resources not always easy to scale

- Mobile users
  - Location dependencies rather than “arbitrary” function placement as a function of RTT
  - Local orchestration
  - Responsibility in on mobile devices

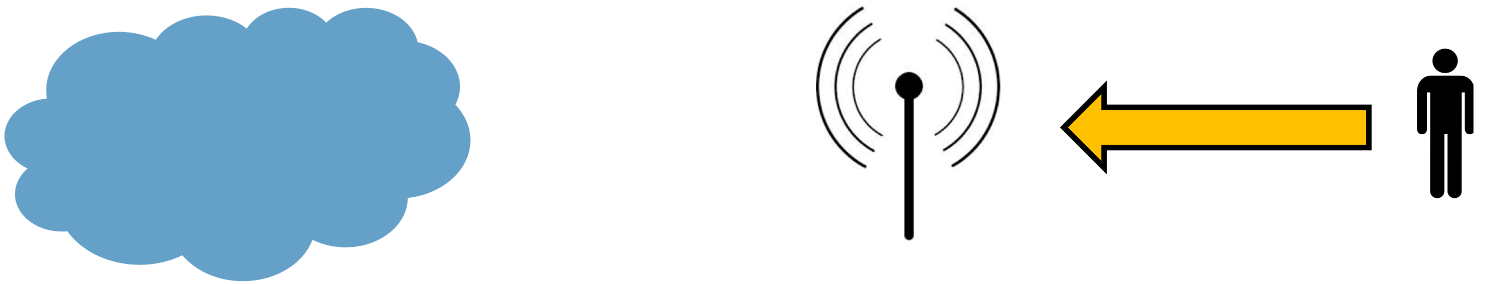
- Decomposition
  - Reusable – possibly stateless – functions
  - Fine granularity
  - Dynamic instantiation of processing graphs (DAGs)

Two models to provisioning

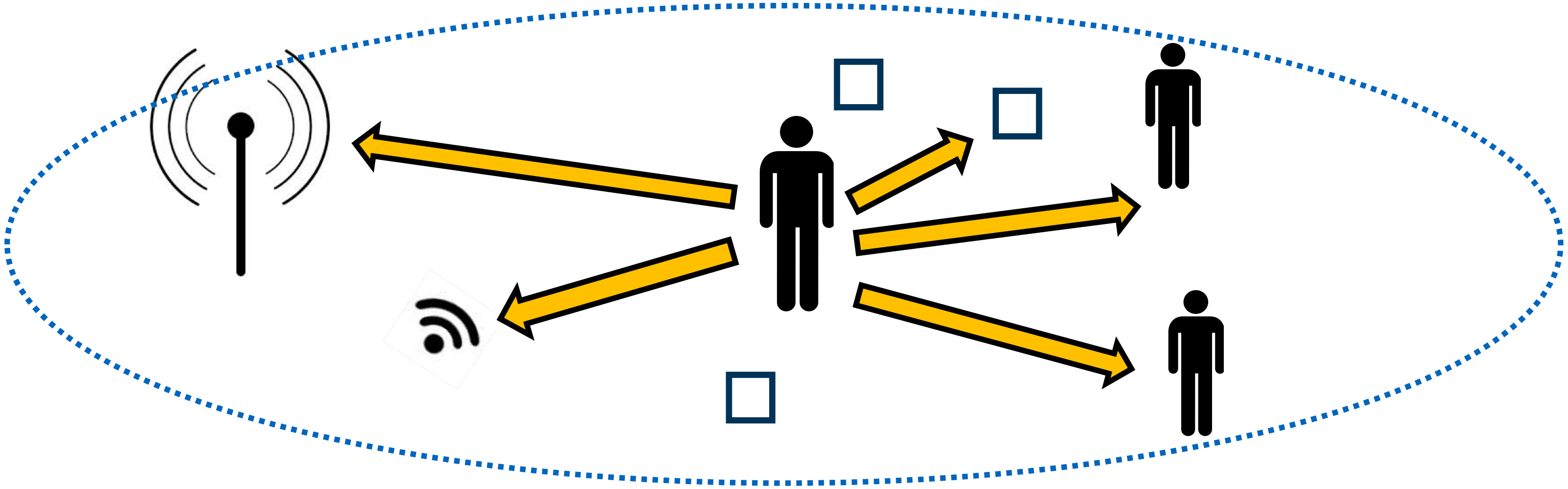
- Cloud-driven operation
  - CDN-style: Functions being pushed from the cloud towards the user
  - Doesn’t change the fundamental nature of centralized operation



- User-/Device-driven operation
  - Functions are received from and invoked by the user on demand



User-driven model



- Searching for devices in the vicinity
  - Access points, cell towers, embedded systems with computing power
  - Sensors and actuators
- Discovery and service / function identification
- Service composition by combining functions from devices
- Mobile code execution by pushing functions to devices

Two Examples

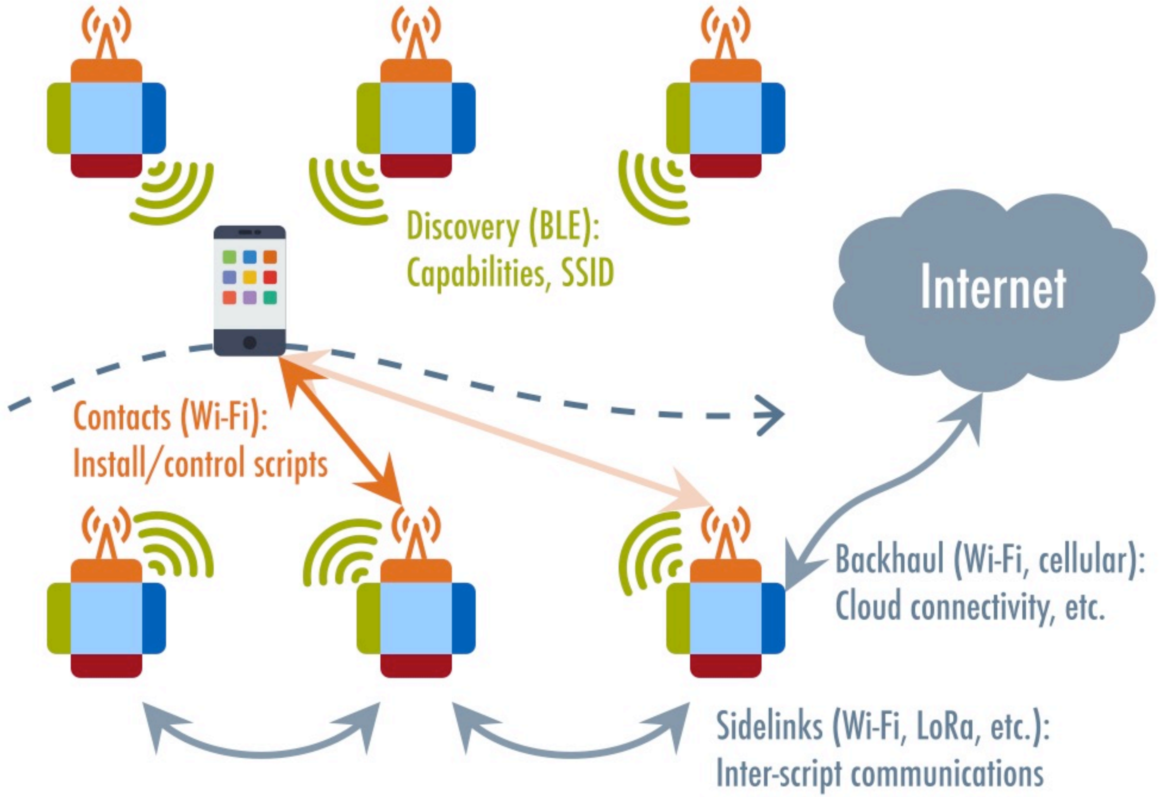
1. Lua-based mobile code execution
2. Trigger-action framework leveraging Bluetooth Low Energy Beacons for networking

Commonalities

- Client-driven
- Microcontrollers
- Broadcast networks with strictly local discovery
- (Extension via Internet feasible but not yet integrated)

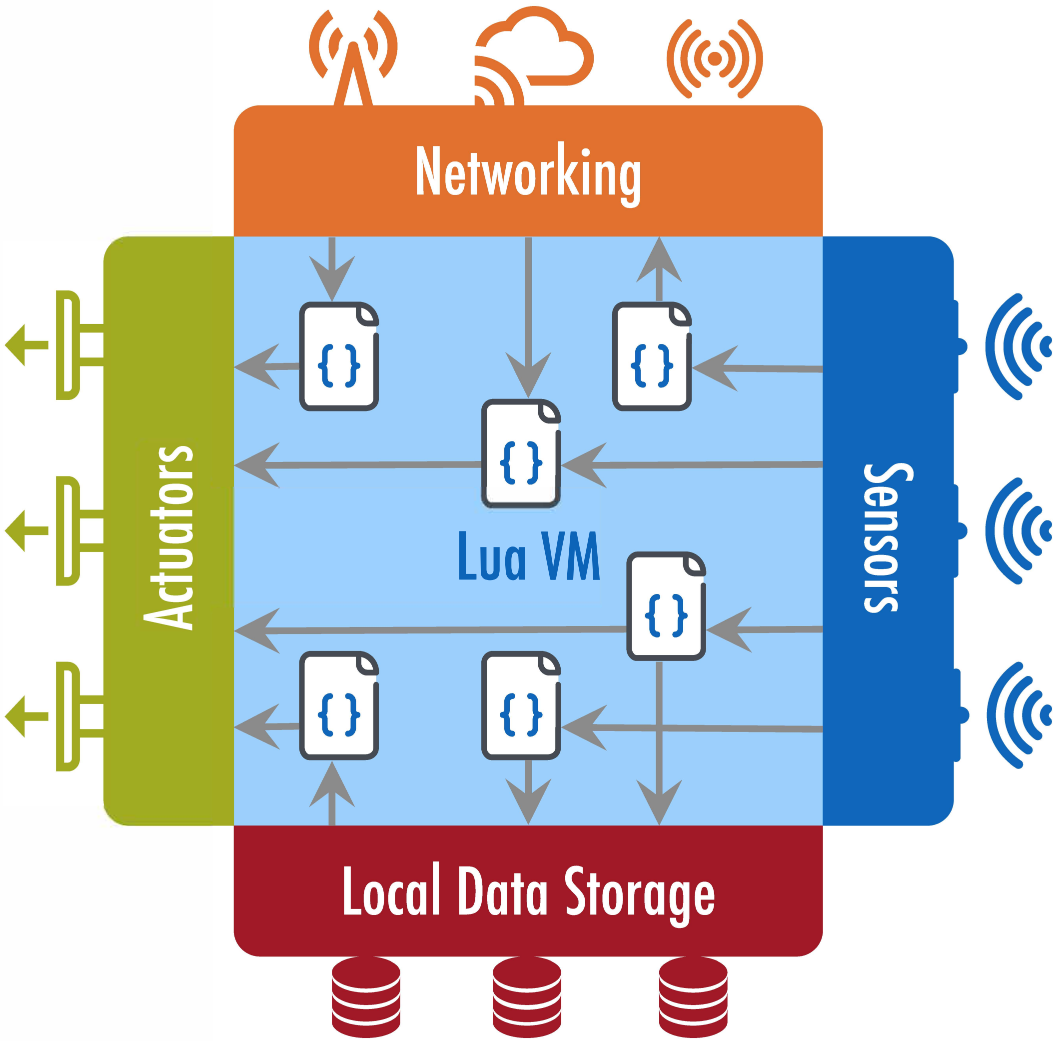
1. Lua-based Mobile Code Execution

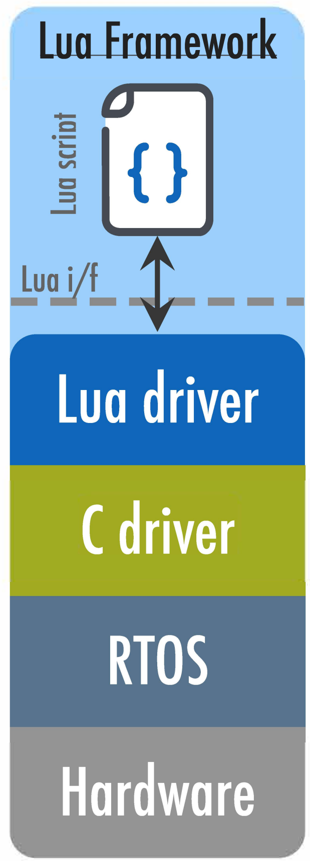
- Instance of a mobile, pervasive computing environment



Fiona Guerin, Teemu Kärkkäinen, Jörg Ott: **Towards a Programmable World: Lua-based Dynamic Local Orchestration of Networked Microcontrollers.** Proc. of the ACM MobiCom Workshop on Challenged Networks (CHANTS), October 2019.

Node architecture





Basics and operation

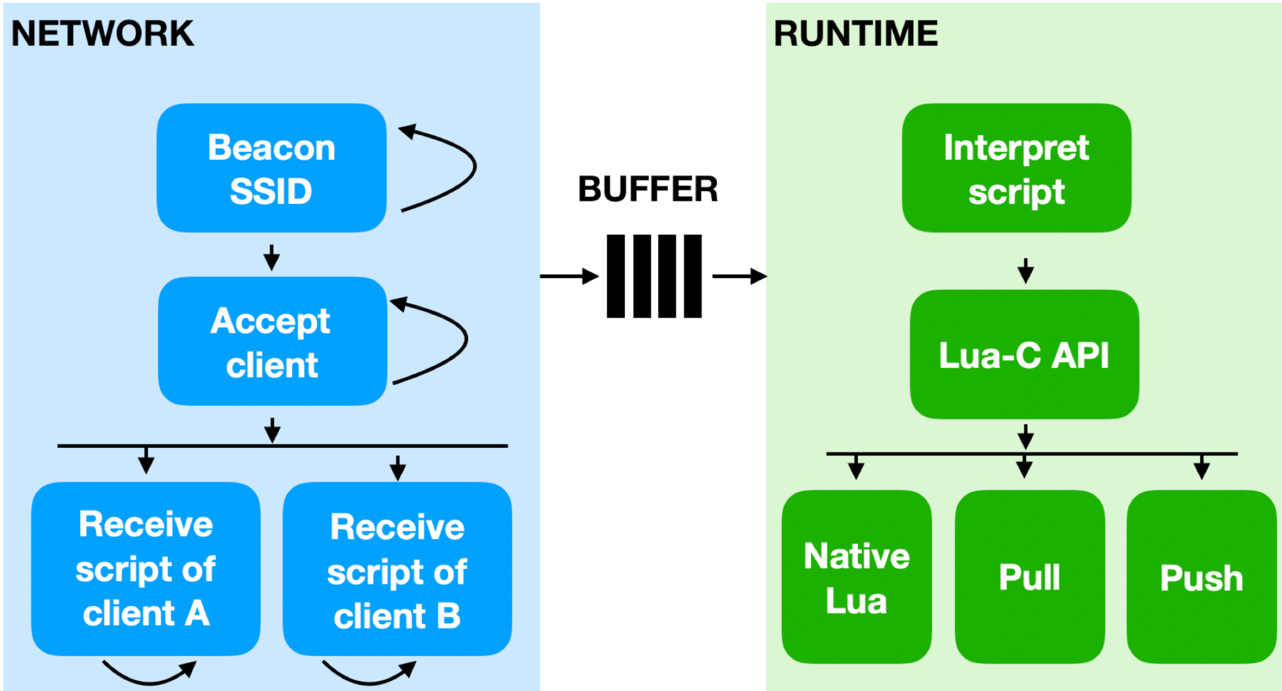
- Lua Process VMs: Generic execution platform
- Sensing + actuation hardware: Node-specific capabilities

- Function properties: node capabilities
  - Nodes beacon their capabilities + rendezvous information (= SSID)
  - Functions contain metadata expressing dependencies
  - 2-stage matching

- Mobile node as orchestrator
  - Picks devices
  - Transfers mobile code – instantiation governed by the executing node
  - Collects results

- Different operation modes for code
  - Pull for one-time operations
  - Push for repeating readings

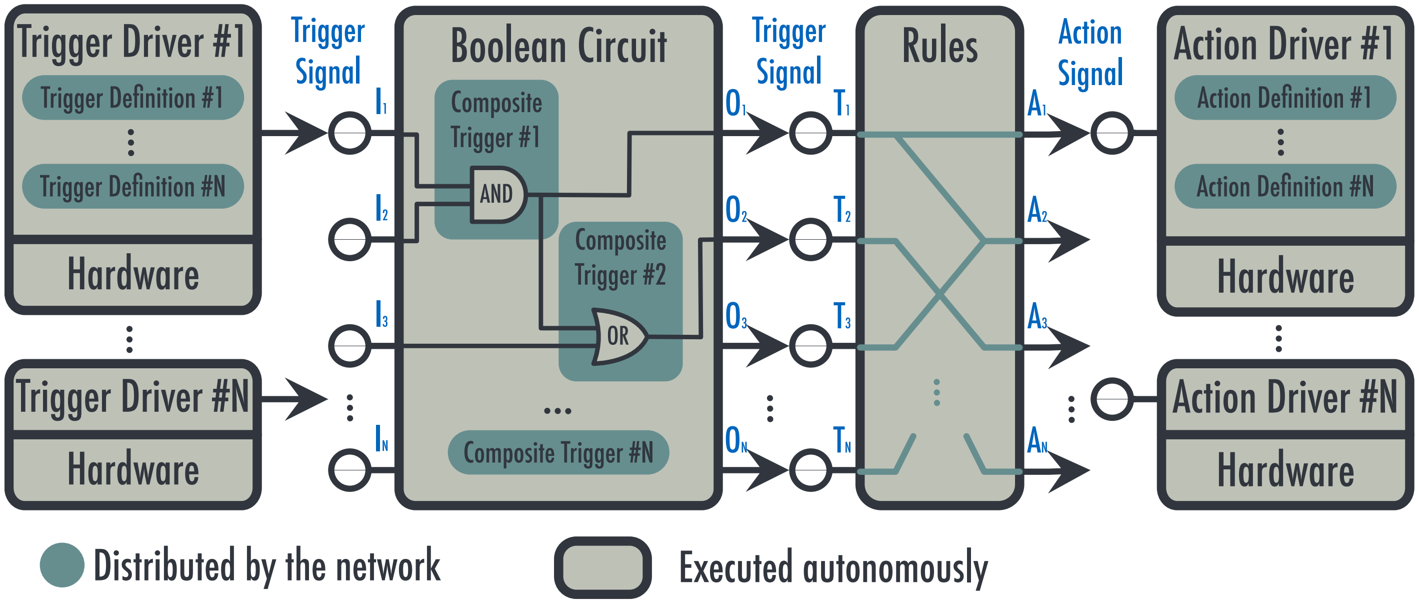
Basics and operation (2)



- Some prototype observations (ESP32)
  - Discovery and code transfer dominate execution time
    - Can be amortized across multiple scripts
    - BLE + Wi-Fi efficiency have an impact, so does device density
  - > 100 concurrent clients with reasonable tasks feasible

2. Distributed Trigger-Action Framework

- Flexibly programmable smart environments
- Distributed variant of IF-THIS-THEN-THAT (IFTTT)



Leo Fuchsloch, Teemu Kärkkäinen, Jörg Ott: **Trigger-Action Computing in Local Broadcast Beaconing Networks.** Proc. of the ACM CoNEXT Workshop on on Emerging in-Network Computing Paradigms (ENCP), December 2019, to appear.

Basics and operation

- Model comprising trigger and actions
- Flexibly combined by program logic as minimal mobile code
- Function properties: (Type ID, instance ID) | (Definition ID)
  - Drivers have custom APIs, need to ensure matching signals
  - Metadata messages to announce capabilities
- BLE beacons as a bus system
  - To discover nearby devices
  - To learn about system capabilities
  - To spread rules
  - To distribute signals and thus cause actions
- Extreme case: Moving only computation, no data
  - Minimal data conveyed implicitly in the data
  - Larger data volumes could use auxiliary communication channels

Protocol messages

- Triples: (type, length, type-specific part)
- Trigger / action definitions

Definition ID	Type ID	Instance | *	Type-specific

e.g. (red, green, blue)

- Rule definitions

Rule ID	Trigger ID	Action ID

- Trigger signals

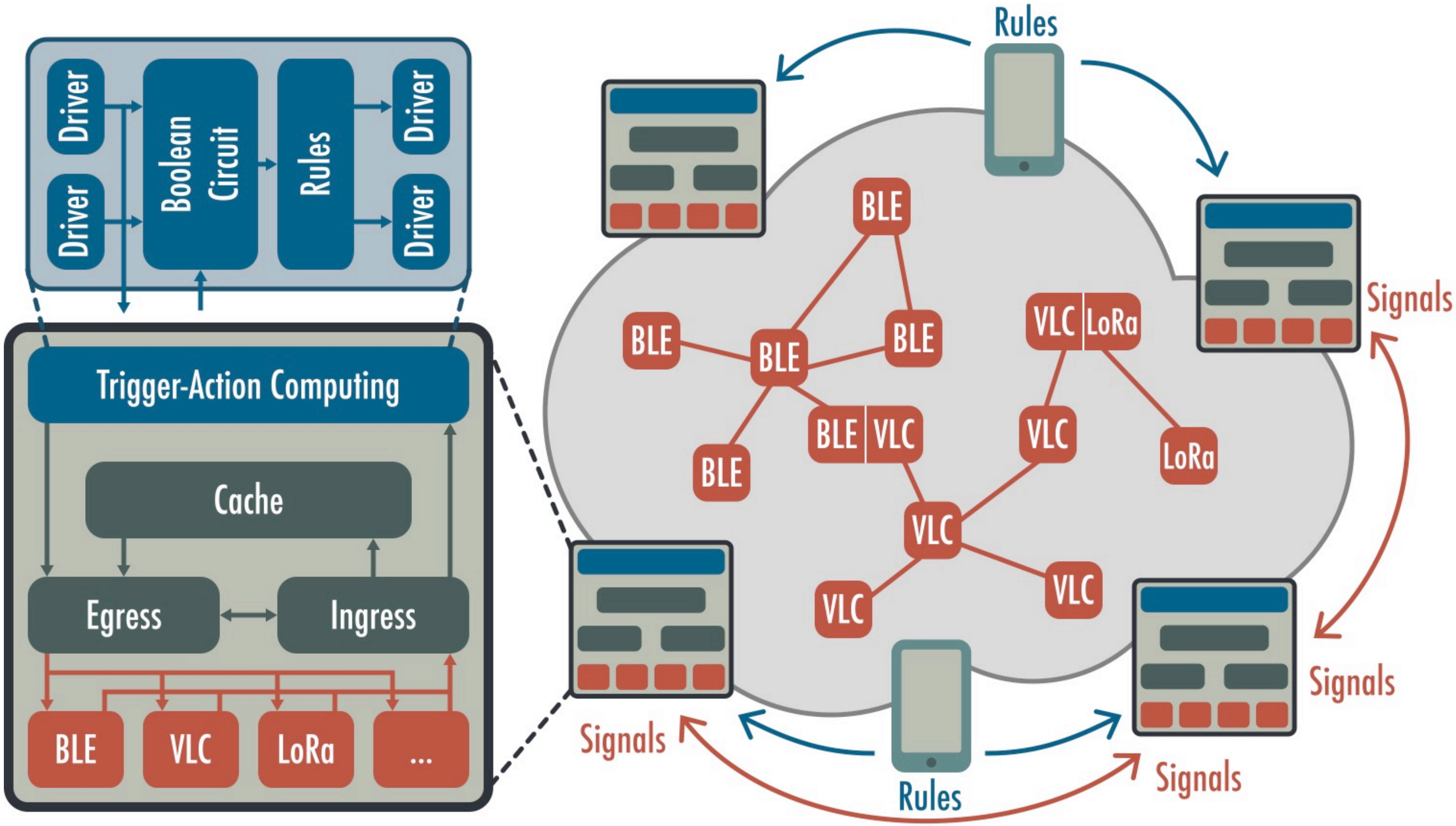
Type	Seq #	Type-specific

list of trigger IDs | Bloom filter

- Descriptor

Device metadata

Basics and operation (2)



In-network compute operation

1. Function properties

int f(int a, int b);

char *h (float e);

int g(char *c1, char *c2);

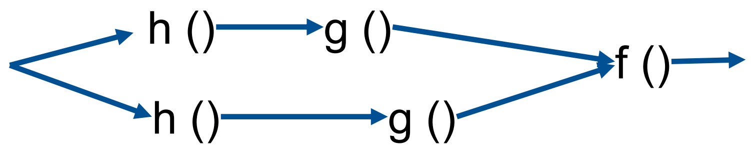
2. Discovery

g () g () g () g () g ()

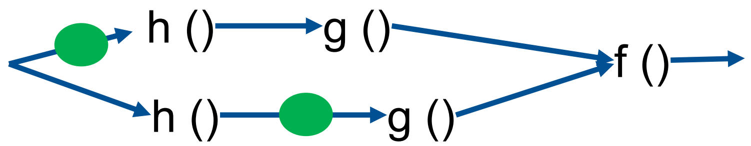
3. Choice / Placement

g () g ()

4. Orchestration



5. Execution



In-network compute operation

1. Function properties

2. Discovery

3. Choice / Placement

4. Orchestration

5. Execution

Identification
- Name-based (type [,instance])
- Attribute-based
- Implicit (w/ mobile code)

Parameterization: input, output
- Implicit

Requirements / dependencies
- Implicit
- Dedicated interpreter

In-network compute operation

1. Function properties

2. Discovery

3. Choice / Placement

4. Orchestration

5. Execution

Many flavors of service discovery

- Broadcasting / multicasting
- Anycasting
- Directories
- Function / service routing
  - After mapping
  - Named-based

Broadcast network

- Beaconing
- Probing

In-network compute operation

1. Function properties

2. Discovery

3. Choice / Placement

4. Orchestration

5. Execution

Different scopes

- Network-wide
- Regional
- Local

Orchestrator vs. client

Resource consent

Client-driven

- Discovery-based choice
- Function invocation
- Code instantiation

In-network compute operation

1. Function properties

2. Discovery

3. Choice / Placement

4. Orchestration

5. Execution

Different scopes

- Network-wide
- Regional
- Local

Orchestrator vs. client

Degree of self-orchestration

Client-driven

- Construction of a process pipe
- Explicit by arranging functions
- Implicit via a bus

In-network compute operation

1. Function properties

2. Discovery

3. Choice / Placement

4. Orchestration

5. Execution

Execution of functions

- “Server” instances waiting for calls
  - Continuously running
  - Dynamically instantiated

Data flow

- Point-to-point transport
- Encapsulated in beacons

Program flow

- Via orchestrator call sequence
- Via addresses in beacons

Conclusion

- In-network computing for broadcast networks
  - Compute, storage, and networking in each node
  - Beyond a distributed system as network complexity grows
  - Different levels of abstraction and expressiveness
  - Even small code sniplets may suffice

Two meta aspects = challenges

- Pushing control into the network
  - Moving away from a central coordinator constantly in charge
  - Autonomous in-network operation of program logic
- Abstracting composability via API signatures
  - Which outputs can connect to which inputs
  - Need more than a Unix or packet pipe model
  - Data + metadata