Resource and Service Management in Fog Computing

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Introduction

Insufficiency of cloud for new generation applications e.g. IoT:
- 6 Vs of Big Data: Volume, Velocity, Veracity, Variety, Variability, and Value.
- Lack of support for latency-critical applications.
- Insufficient support for bandwidth-intensive applications.

Fog Computing:
- Heterogeneous fog nodes deployed closer to data sources.
- Complementary to cloud.
- Facilitates location-sensitive, context-aware, and localized applications.
- Dynamic environment supporting mobile fog nodes as well as frequent join/leave of nodes.

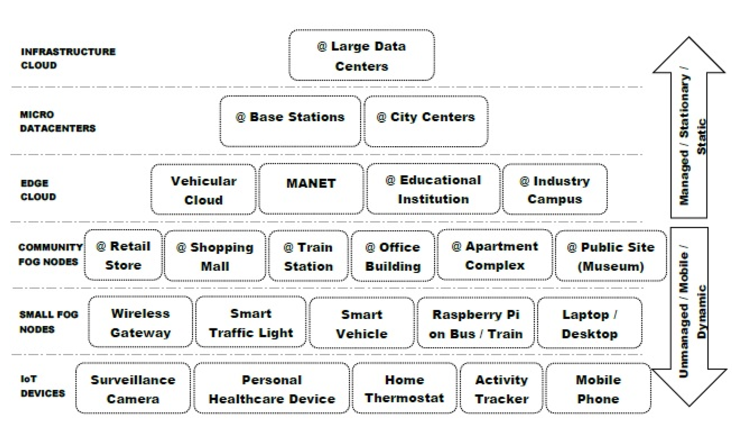

Figure 1: Various types of prospective fog nodes in smart city environment.

Factor	High Fog Layer	Low Fog Layer
Node capacity	High	Low
Network type	Homogeneous	Heterogeneous
Network bandwidth	Low	High
Network latency	High & Variable	Low & Predictable
Power availability	Continuous (Plugged)	Intermittent / Battery-powered
Mobility	Stationary	Stationary / Mobile
Geographic dispersion	Co-located	Dispersed
Geographic scope	Covers larger areas	Localized
Elasticity	Low	High
Security / Privacy control	Low	High
Physical environment	Managed	Unmanaged public / personal

Table 1: Factors defining hierarchy in Fog.

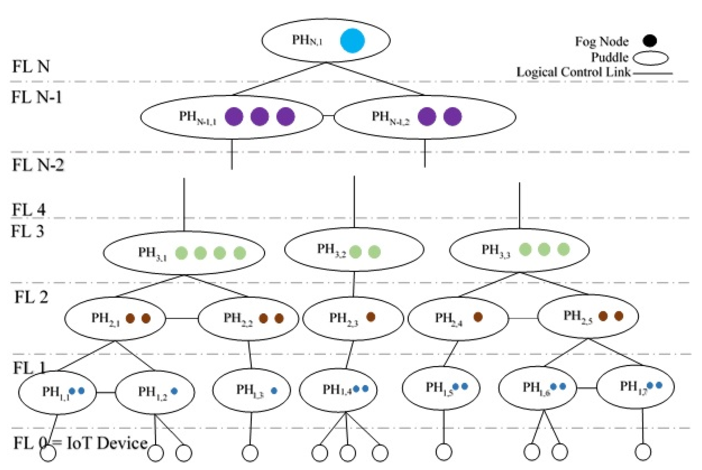

Figure 2: PuddleTree comprising fog nodes with varied resource configurations.

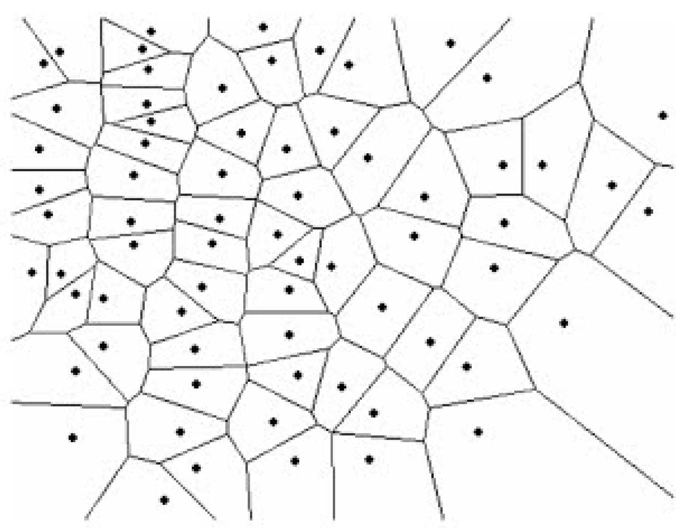

Figure 3: Voronoi Structure based Geo-partitioning

Hierarchical and Autonomous Fog Architecture (HAFA)

- Proposed architecture for the organization of heterogeneous fog nodes into logically connected multi-layered hierarchical fog environment for improved load balancing, fault tolerance, and autonomy.
- Grouping of fog nodes (Puddle) belonging to a specific layer using clustering method for resource pooling and local control (PuddleHead).
- Logically linking groups of fog nodes from different layers (Parent-Child relationships) to facilitate disaster readiness, ad hoc deployment, and distributed control over extended area. It also helps reducing effort in finding an optimal node with required resource characteristics for deployment of a service.
- Logically linking groups of fog nodes from same layer (East-West control links) to facilitate lateral handoff of workload during overflow and failover during disaster scenarios.
- Control links maintained independently by all the Puddles in system together form a distributed tree-like structure (PuddleTree).

Feature	Proposed Fog Architecture	Other Fog Architectures
Structure	Multi-layered hierarchy.	Flat.
Management	Distributed.	Centralized.
Dynamicity / Elasticity / Scalability	Grow / Shrink. Effective tracking using Puddles.	Static. Difficult to track in global database.
Node heterogeneity	Takes advantage of heterogeneity.	Treated homogeneous.
Generic architecture	Yes. No assumptions regarding system configuration. Can be readily tailored for specific environments.	No. Assumptions regarding node types, hosting costs, mobility, physical location, etc.
Knowledge of complete system state	Not required.	Required.
Resource pooling	Supported by Puddles	Not supported. Individual fog nodes only.
Disaster readiness	Supported by distributed local control.	Not supported.
Locality support	Supported by Puddles.	Not considered.
Cloud integration	Supported, but not required.	Required. Not discussed.

Table 2: Feature comparison of various fog architectures.

Initial Service deployment in Fog

- Proposed Voronoi structure based geo-partitioning of a given area with fog nodes as sites.
- Area of influence of fog node is defined by its Voronoi region.
- Fog node assigned to a region is best choice to serve service requests from co-located IoT devices and users.

Resource Management in Fog - Challenges

- Heterogeneous fog nodes with varied resource configurations.
- Number of nodes in a fog environment is of several orders of magnitude more than that in a cloud.
- Widely dispersed over large geographic areas, possibly individually at unmanaged sites.
- Dynamic fog environment resulting from energy-constrained nature of fog nodes, node mobility, and frequent node join/leave to support variable local workload.
- Significance of geolocation of fog nodes to support location-sensitive, context-aware applications and those of only local value.
- Placement of fog nodes at unmanaged sites results in lower reliability.

Service Management in Fog - Challenges

- Energy-constrained nature and mobility of fog nodes result in increased frequency of service deployment requests.
- Mobility of IoT devices, users, and fog nodes necessitate frequent migration of application services and data to other fog nodes.
- Incomplete knowledge of system state, renders centralized solution approaches infeasible.
- Data dispersed over different compute and storage nodes.
- Significance of individual instances of a given service based on the hosting fog node geolocation.
- Cost-optimal deployment of services balancing the utilization of low cost cloud and higher layer fog nodes as well as high cost lower layer fog nodes.

Preliminary Results

- Hypothetical smart city dataset with 781 prospective fog nodes includes five types of fog nodes, each represented by a fog layer, and vary in resource configuration and mobility characteristics.
- Fog nodes belonging to each layer represented by a unique color.
- Nodes belonging to same fog layer are grouped into Puddles using Agglomerative Complete Linkage Hierarchical Clustering approach.
- Parent-child relationships among Puddles in adjacent layers are formed using Complete Linkage method.
- HAFA facilitates fully distributed resource management and allocation, using local system state knowledge.

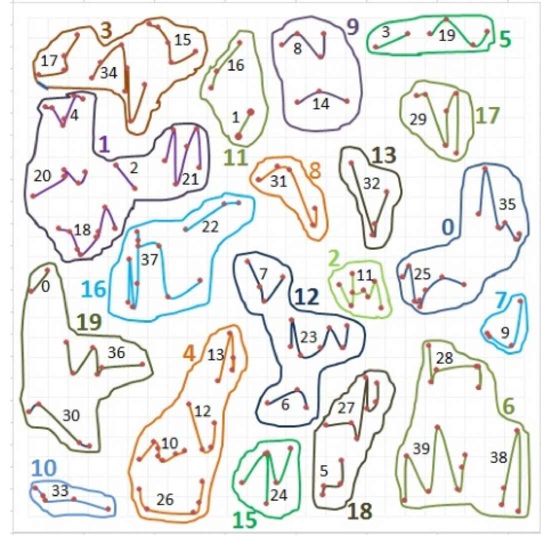

Figure 3: Parent-Child relationships between fog layer-3 and fog layer-2.

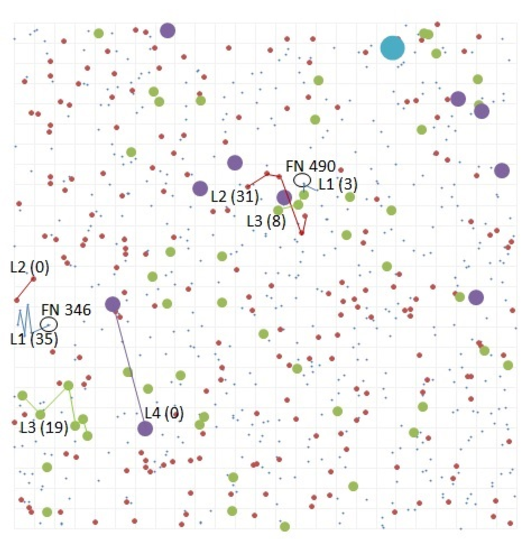

Figure 4: Search for nodes.

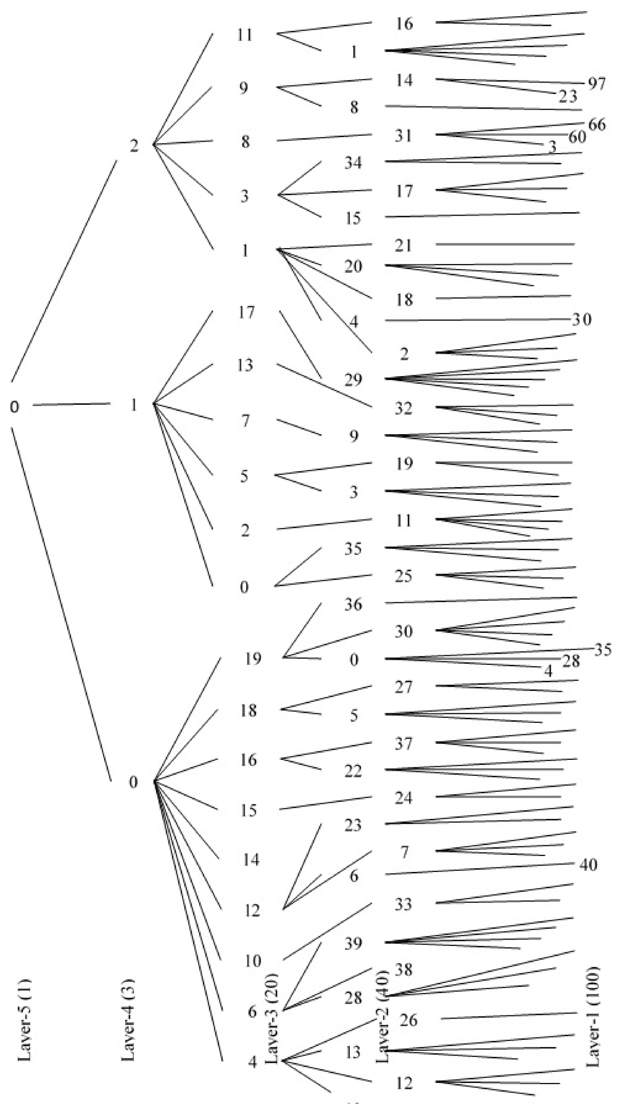

Figure 5: PuddleTree representing connected fog hierarchy.

Work in Progress

Working on research problems (assuming pre-deployed fog infrastructure):
- Application service placement in fog satisfying resource and QoS requirements as well as optimizing node utilization, network utilization, service execution cost, energy consumption, performance, availability, and load balancing.
- Application service migration in fog considering similar factors as above while minimizing impact on user-perceived performance.

Developing PuddleSim (Simulator):
- Event-based simulator extended from iFogSim and CloudSim.
- Supports mobility of IoT devices, fog nodes, and users.
- Supports multi-layered hierarchy of heterogeneous fog nodes.
- Supports organization of fog nodes into Puddles.
- Facilitates testing of various service deployment strategies and application environments.

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