Geolocation Compass: Geolocalized Data Registry and Forwarding for ICN Networks

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Abstract

Information Centric Networking (ICN) defines a new paradigm for networking focused on retrieval of content regardless of source endpoints, allowing the network to determine from where content objects should be retrieved. This mechanism relies on all content being consistent regardless of geographical location and mobility.

In a future with pervasive Internet of Things (IoT), especially a plethora of *mobile* things, ICN's clean and simple mechanism may not be enough in cases where data is geographically or spatially relevant. For example, in cases where a user wants wind speed at 1000 feet instead of 10,000 feet or sea level or requesting data from a traffic camera at a particular cross street.

To solve this, we propose an end-to-end Geolocation Compass service that forwards Interests based on a range of XYZ coordinates (Latitude, Longitude, and Elevation) and registers geolocalized services with Geolocation Compass nodes. The solution covers both consumer and producer mobility.

A single producer can have multiple registered services, such as a multi-purposed weather sensor (temperature, humidity, atmospheric pressure, etc.). Each service offered could have different ranges of relevance, depending on the data involved.

Consumers send Interests using geolocation coordinates of the Point of Interest (POI) and a Search Radius for a Region of Interest (ROI), which is optional. The network performs best fit to that geolocation and if there are multiple destinations, the network satisfies the Interest with a response that fits the criteria.

Producers format the content object with geolocation specifics or ranges of service relevance. The coordinates can be used for providing location specific data to a consumer based on POI and ROI, either based on consumer's current location or a remote location.

Keywords

Information-Centric Networking, Geolocation, Named Data Networking, Geolocalized Services and Data, Geolocation-aware Forwarding, ICN-in-ICN tunneling, Wildcard-based Forwarding, IOT, Local Services Registry, Scalability

1 Background

Today, information is centralized, cached and not easy to localize, synchronize, manage, or update. Producers are at the mercy of inaccurate and imprecise geolocation services to resolve IP address blocks to zipcodes. Producers also must rely on centralized intermediaries to take their services to consumers. Additionally, producers may need to pay for ranking privileges and are dependent on intermediaries for accuracy and timeliness of their data.

Currently, consumers get filtered access to non-realtime data and possibly only a subset of relevant producers in a localized area based on business preference or interests of intermediaries. This indirect mechanism disassociates producers and consumers, requiring an intermediary for data exchange while adding overhead in data timeliness, accuracy, and traversal costs. Registries and portals can still be centralized, but consumers and producers can better utilize granular, geolocalized information using ICN.

This paper proposes a mechanism called Geolocation Compass that forms a conduit directly from consumers to producers for realtime relevant and geolocalized data access while eliminating intermediaries where they do not enhance value of the service offering.

In ICN networks, semantical namespaces are flexible and extensible. Geolocation Compass leverages this extensibility to embed geolocation information in the network, unlocking the true power of location-based services.

Geolocalized data can be defined as augmenting content with location data and relevance to a geographic area, whether current location or remote location of interest.

2 Design

Similar in function to a physical compass, Geolocation Compass provides consumers access to requested information by forwarding their Interests to producers that offer them real-time relevant and geolocalized content. Geolocation Compass has an ICN network component and an application component.

The network component of Compass consists of:

- Producers registering services to Compass-aware nodes
- Consumers requesting geolocalized data forwarded to the closest Compass-aware node
- Non-Compass-aware nodes forwarding to Compass-aware nodes

Although application component is an important aspect of this overall service, most of the application aspects are service-specific and are reserved for future application work and out of scope of this paper. These application aspects can relate to data integrity, service associated data, and communication security.

This paper focuses on the network interactions with Consumers and Producers. Routing algorithms to support geolocation forwarding are reserved for future work.

The ubiquity of delivery is a core principle of the ICN paradigm. Consumers shouldn't care what host delivers content as long as content authenticity is proven. Geolocation Compass conforms to that principle: as long as content is real-time, geolocalized and relevant, the host doesn't matter to the consumer.

2.1 Geolocation Compass Registration

Producers offer their localized services by registering them to their nearest Geolocation Compass node by sending a Compass Register Request. Producers are authenticated by a Challenge mechanism before their services are admitted into the Geolocation Compass. Multiple services can be registered within a single Register Request message using the same geolocation coordinates for the service relevance area of coverage.

The entries in the Registration Table are based on Service IDs and exist on nodes that have registered services. Any node can potentially have producers registered and, therefore, all Geolocation Compass nodes must support Registration Table functionality.

All Producers advertising the same service will have entries listed under that Service ID in the table. The responding geolocation node collates information across all producers that match a requested Service ID within the Region of Interest. This list may be delivered in a form similar to an ICN Manifest.

Table 1: Example of Fields and Values in Geolocation Compass Registration Table

Service Identifier	Geolocation Coordinates	Serving Radius (meters)	Registration Validity (Epoch)	Producer ID
Temperature	x,y,z	100	1489516340+600	P1
	x1,y1,z1	100	1489516340+600	P2
Humidity	x1,y1,z1	100	1489516340+600	P2
Business Hours	x2,y2,z2	1000	1489516340+43200	P3
Traffic Conditions	x4,y4,z4	800	1489516340+60	P5

Service Identifier is the global identifier for well-known Geolocation Compass services.

Geolocation coordinates provide the latitude, longitude and elevation of the Producer offering a service.

Serving Radius is the geographical area within which the service data is relevant as defined by the Producer.

Registration Validity defines the lifetime for which the Producer's registration for a service to the network node. The Producer is expected to refresh the registration prior to expiration of the lifetime for each registered service. Otherwise, the entry is cleared upon expiration.

Producer Identifier is the transport identifier or an indirect pointer reference for a transport identifier.

Note: *transport discovery and transport identifiers are out of scope for this paper.*

Note: *Security aspects regarding Geolocation Compass applications and are reserved for future work.*

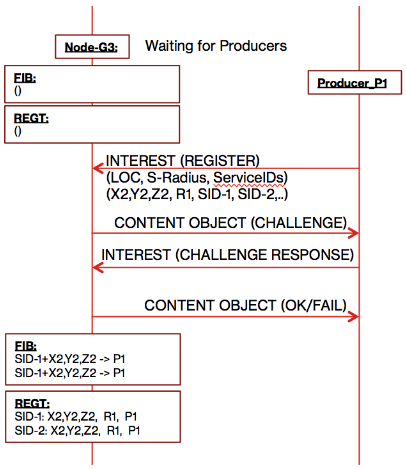

Figure 1: Geolocation Compass Registration Flows

2.2 Forwarding for Compass

Geolocation Compass impacts forwarding of Interest Messages while the reverse path conforms to standard ICN operation. Geolocation Compass proposes forwarding of Interests within Compass-aware nodes to the nearest neighbor in the direction of the geolocation specified in the Interest.

Two options for Interest Messages were considered: Namespace modification or TLV. We recommend namespace modification. This requires a subset of nodes to support Geolocation-based Forwarding. Adjacent nodes that lack this support can have static forwarding entries or advertised wildcard routes that point to nodes with such support.

The namespace label can be used for other types of custom namespace. Geolocation Compass recommends using a single identifier for all Geolocation Forwarding (GEO).

Having the namespace label as the leftmost name alerts label namespace aware devices about special handling of lookups. This position also allows for wildcard matching for lookups on nodes that are not aware of the labeled namespace.

Node-I = Current ICN Node (no support for Geolocation Forwarding)

Node-G = ICN Node with Geolocation Forwarding support

Proposed namespace format:

```
/<Label>/<Service_ID>/<Location>/<namespace>/

<Label> : Node-I to Node-G

<Service_ID> + <Location> : Node-G  to Node-G

<namespace> : Producer namespace

/GEO/BusinessHours/GC=39.008756,N,
77.470131,W,82.4,M,33.9,M/ACME
```

2.3 Geolocation Format

Any standard format like NMEA-defined can be used for Geolocation information (latitude, longitude, altitude).

```
39.008756,N, 77.470131,W,82.4,M,33.9,M

Where:

     39.008756,N Latitude 39 deg 00.8756' N

     77.470131,W Longitude 77 deg 47.0131' W

     82.4,M      Altitude, Meters, above mean sea
level

     33.9,M      Height of geoid (mean sea level)
above WGS84 ellipsoid
```

The location could be stated in absolute terms or in a variable format from a reference point by varying each of Latitude, Longitude, and Altitude as independent or dependent variables or within a range for each value.

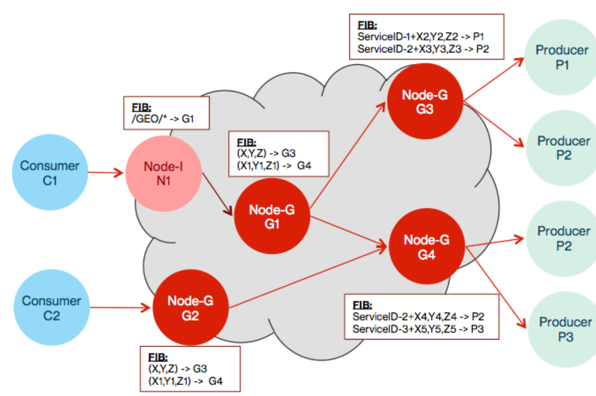

Figure 2a: Geolocation Forwarding with FIB examples for intermediate nodes

2.4 Forwarding Path

On non-GEO enabled forwarding nodes, a Forwarding Information Base (FIB) entry points to the nearest GEO-enabled forwarding node. Non-GEO nodes can be provisioned with GEO-node reachability or GEO-enabled forwarding nodes can advertise their reachability to non-GEO enabled nodes. The provisioning or advertising is achieved by using the namespace label and wildcard, /GEO/* and hence any namespace lookup on these non-GEO nodes will be forwarded to a GEO node (refer to *Figure 2a*).

Interest messages can be encapsulated with the namespace of a GEO-enabled node using a Geolocation-aware Routing Protocol session to another GEO-enabled node (ICN-in-ICN encapsulation). By encapsulating an Interest in another Interest, a GEO-based Interest can be tunneled across ICN nodes that do not support GEO-based forwarding.

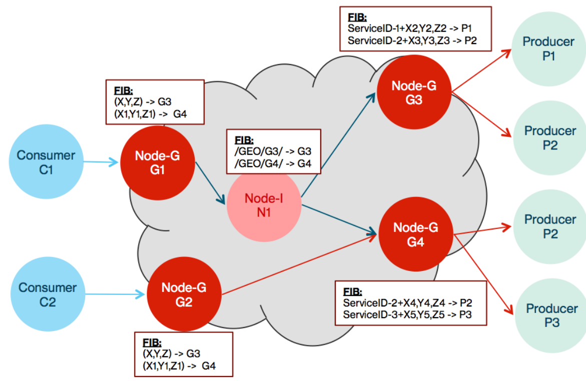

Figure 2b: Geolocation Forwarding over non-GEO intermediate nodes

In *Figure 2b*, G1 is not directly connected to its GEO neighbor G3. G1 encapsulates the original Interest Message with an outer Interest message using G3's namespace. N1 performs normal ICN forwarding to G3.

When G3 receives the outer ICN message, the encapsulation is removed and it performs a lookup based on the inner Interest message.

In the reverse path, similar encapsulation would have to be applied, i.e., G3 tunnels to G1.

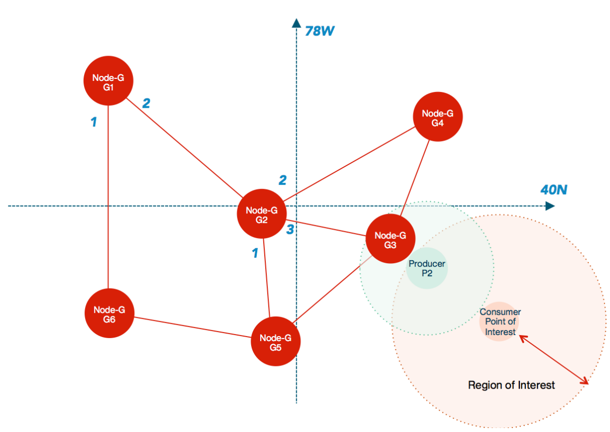

Figure 3: Geo-based Forwarding Decisions

In *Figure 3*, G1 has two GEO entries: Face 1 for G6 and Face 2 for G2. On receiving an Interest for GEO=39,N,77,W, G1 performs a GEO lookup and determines that it does not have a Face for any GEO node that falls within the ROI. It then performs a calculation to determine that G2's coordinates are closest, and forwards Interests to G2 out Face 2. Similarly, G2 performs the same set of actions to forward the Interests to G3. G3's lookup provides a match for the registered service that satisfies the POI/ROI in the Interest.

If the node global table is manageable, all nodes can have their geolocation coordinates advertised and stored in a GEO FIB. In this scenario, every GEO lookup resolves to a best next-hop. When the entire network is GEO capable, these GEO lookups will be hop-to-hop without need for tunneling. While in transition, the ICN-in-ICN tunneling mechanism described earlier extends to a single tunnel to the ultimate GEO hop.

To achieve better scale of services and efficient handling of mobile producer transience, propagating Service IDs throughout a GEO network is not recommended under this proposal. Instead, GEO-enabled nodes use POI/ROI from from the Interest messages and neighbor nodes in the FIB to perform lookup matches or proximity calculations to forward towards the consumer's POI/ROI.

The node with services registered forwards Interest messages based on service ID and ROI matches in the FIB, as shown in Figure 4 and Figure 5.

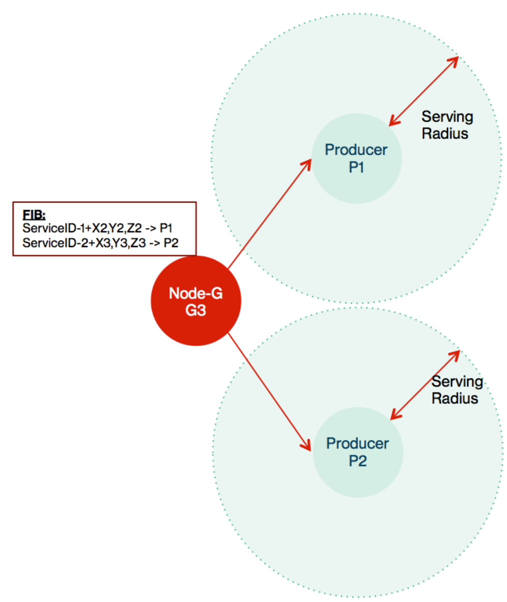

Figure 4: Geolocation Forwarding with FIB on Edge nodes

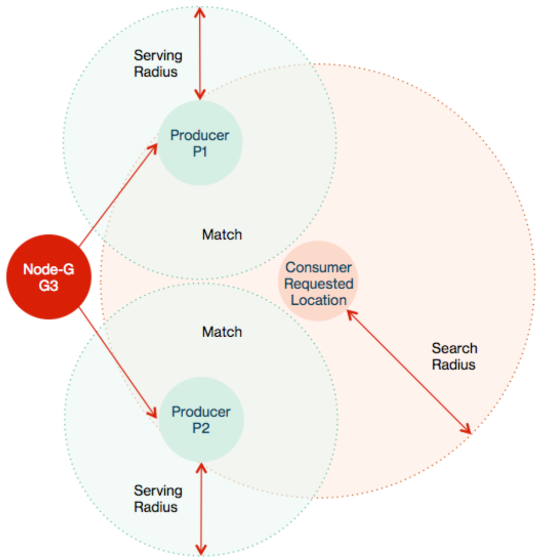

Figure 5: Consumer Search Radius

2.5 Community Guides

Community Guides are searchable services that provide real-time relevant and geolocalized data leveraging Compass' Service ID capability.

For example, business hours can be tied to a smart environmental, lighting or security system/node or a smart door lock. There is no mechanism to register to a geolocation aware network and dynamically update this data. For a consumer, this information can be universally available without going through a cloud-based service.

Another example, traffic cameras or signals or dynamic traffic control devices can be accessed in real-time by approaching vehicles (especially autonomous) where an ICN-enabled device can provide a single copy of video, status or other data to any vehicle within reach instead of unicasting to each receiver and storing traffic content in a central data repository with network delay end-to-end.

2.6 Relevance Radius - Geofencing

Relevance Radius has two dimensions: a producer radius for services and a consumer radius for searching.

Producers can define a radius of relevance for services at the time of Registration. This radius indicates the geolocation scope of the data produced.

Likewise, consumers can define a search radius in the context of a POI, which forms the ROI, when requesting information through Interest messages for Geolocation Compass. This ROI is used by Compass nodes to identify relevant producers that satisfy Interests from consumers. Areas of intersection between the ROI and Producers' Serving Radius determine matching criteria.

Additional algorithms can be constructed to rank producers based on areas of intersection with the consumer ROI.

3 Summary

Geolocation Compass leverages ICN paradigm to provide a scalable and distributed mechanism for efficient access to real-time relevant and geolocalized data. Consumer requests for content are forwarded using geolocation-based routing algorithms to Compass nodes closest to relevant Producers. Namespace modifications are proposed to facilitate routing from non-Compass nodes to Compass nodes and between two Compass nodes as well. Producers can advertise services through Compass nodes using a highly scalable, reliable and extensible Registration mechanism.

Most importantly, Geolocation Compass provides a location-based forwarding plane that serves as a foundation for new application development. The next generation of IoT applications can build upon this foundation to enable a plethora of location-based services.

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5 Acknowledgements

We thank Jean McManus, Verizon Labs Executive Director, for comments that greatly improved this paper.

We thank Nick DelRegno, Verizon Labs Fellow, for input on location-based services.