(3) Active IP Networking: Towards Self-organized Ambient Communication

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DoCoMo Euro-Labs is studying advanced network platforms to integrate diverse access technologies and provide seamless services. Especially the research on end-to-end quality of service focusing on handover between heterogeneous access networks, active and context-aware networks, and ad hoc networks that can interconnect with existing mobile networks.

1. Introduction

Future mobile networks will be called upon to provide seamless services across a variety of wireless access technologies and to support all kinds of scenarios and applications. To accommodate heterogeneous access networks in this way, they should be Internet Protocol (IP)-based networks that are highly extendible and cost-efficient. They must be flexible enough to add new radio-interface technologies and other new technologies like ad hoc networks. They should also be capable of intelligent network operations that can optimize seamless and personalized services according to the current environment. To satisfy all of these requirements, the proposed network architecture uses active and programmable network elements as shown in **Figure 1**.

The following technical problems must be solved to realize these future mobile networks.

- To provide seamless services, end-to-end Quality of Service (QoS) must be preserved when performing handovers between heterogeneous access networks. While various IP-based, end-to-end QoS technologies are now available, their functions must be enhanced to accommodate mobility.
- Context information* must be used sufficiently when providing network services. And to cope with the dynamic nature of context information, active network technology must be applied to improve flexibility in providing network services and to enhance the adaptability of network elements.
- Ad hoc networks must combine with existing mobile networks in a seamless manner through flexible interconnection and addressing systems.

* Context information: Any kind of information that can be used to characterize the state of an entity. An entity may be a person, place, or object relating to the human-computer interaction.

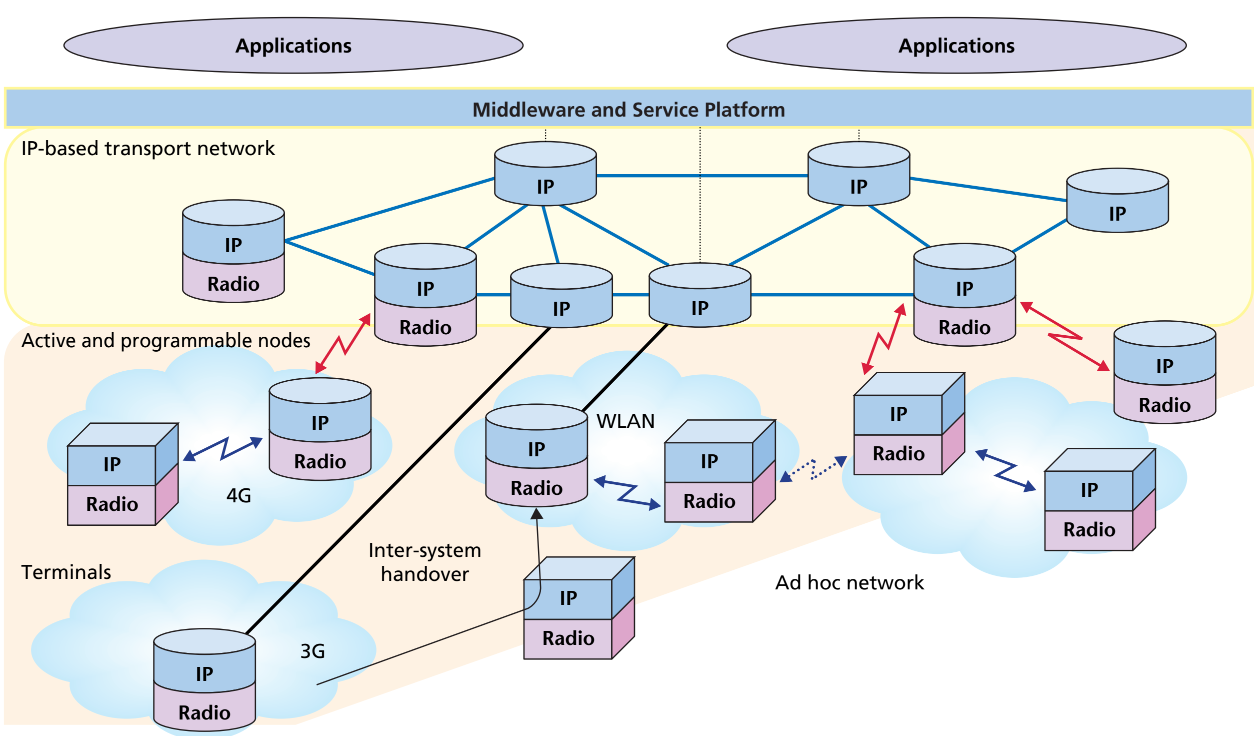

Figure 1 Active IP networking architecture

This article presents new solutions to the above problems.

2. End-to-end Quality of Service

When heterogeneous access networks overlap, it might be advantageous to make a handover to a more suitable Access Point (AP) to provide better services. For example, when passing through a Wireless Local Area Network (WLAN) hot spot, it might be desirable to make a handover to that access point for only a short period of time. In many cases, however, the availability of resources at the potential access point is not known before the handover is performed. To ensure QoS on the data path, there are several techniques such as Differentiated Services (DiffServ) [1] and Integrated Services (IntServ) [2]. In addition, resource management must perform resource admission control, allocation, and releasing in addition to QoS signaling. The IntServ technique performs resource reservation on a per-flow basis, while DiffServ allocates QoS settings or guarantees to flow aggregates configured at network edges. While the resource ReSerVation Protocol (RSVP) [3] is the control plane for IntServ (which may be replaced by a new protocol of the Next Steps In Signaling (NSIS) working group [4]), DiffServ is lacking a control plane. Most current approaches for IP-based QoS signaling protocols like RSVP are not designed to support mobility, and only a few approaches provide support for a single individual handover type [5].

Our research aims to develop a QoS signaling protocol that can support various types of handovers. These include anticipated handover where resources at the new access point are allocated before executing the handover; hard handover where the mobile terminal connects to the new access point after disconnecting from the old one; soft handover where the mobile terminal is connected to both access points simultaneously; and combinations of the above.

The main requirements of a QoS signaling architecture for future mobile networks targeted by our research are summarized here. The architecture:

- Shall not be dependent on specific techniques (such as IntServ and DiffServ) that provide QoS on data paths;
- Shall not be dependent on specific radio access technologies; and
- Shall be capable of supporting various mobility concepts to achieve seamless handovers.

We propose a QoS architecture based on a resource-manager approach that satisfies the above requirements. **Figure 2** shows an example of this architecture. In this example, a mobile terminal connects via an access point to a domain consisting of routers and a Domain Resource Manager (DRM). The DRM (sometimes called a "bandwidth broker") manages the resources of that domain and maintains an up-to-date image of resources and resource reservations in that domain. Furthermore, to reserve End-to-End (E2E) resources, the DRM must request resources from DRMs in adjacent domains. In the case of an anticipated handover, the control signal (1) received via the old

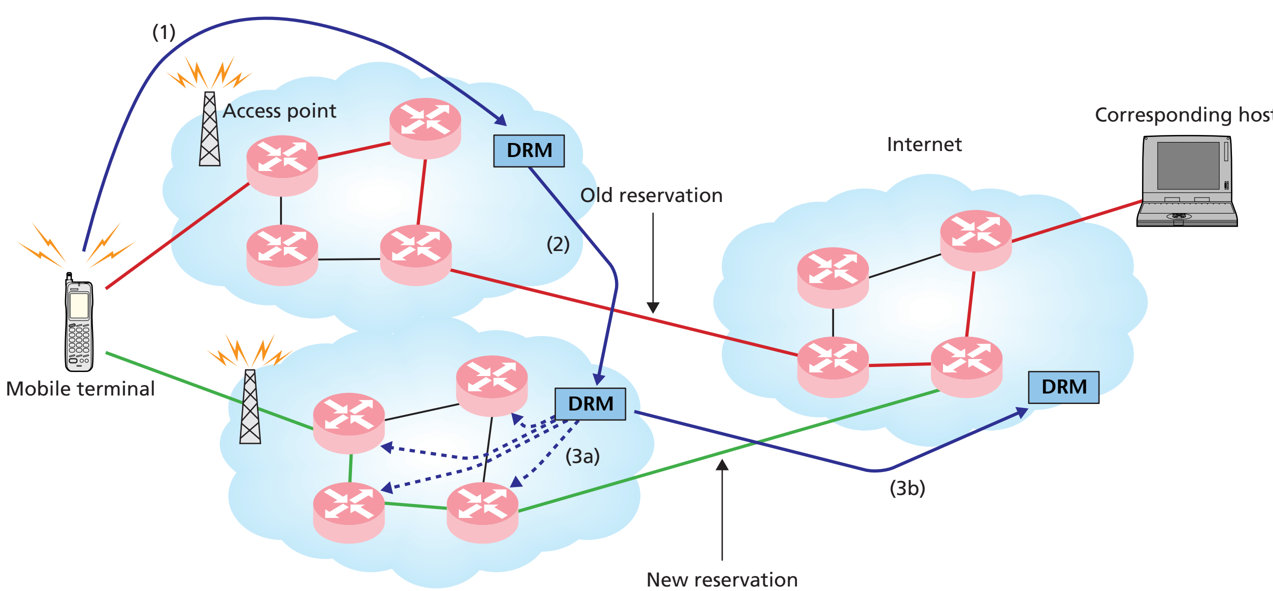

Figure 2 QoS architecture and anticipated handover

access point can be used to provide the new domain's DRM with information (2) related to resource preparation (3a) for the upcoming handover. End-to-end QoS can be preserved here by notifying (3b) yet another domain's DRM that a handover is about to take place. In this way, resources can be reserved before attaching to the new access point triggered either by the mobile terminal itself or by some network intelligence (based on movement prediction, for example).

For our research on QoS protocols, we analyze various types of handovers. For example, comprehensive support of various types of handovers is important for dealing appropriately with a mobile terminal that moves out of a service area and for minimizing subsequent effects on services. It must also be kept in mind that handover performance may differ between different wireless access networks and mobile terminals.

In our research, we have developed an integrated-handover-state model that describes all types of handovers, and based on this model, we have designed and implemented a QoS protocol. A particular feature of this model is that it supports dynamic transitions between different types of handovers, which means that switching between handover types can be performed as needed by control signals no matter what kind of changes occur in the network.

To summarize the above, we have developed an integrated-handover-state model and a new QoS signaling protocol that combines resource management and mobility management [6], [7].

3. Active and Context-aware Networks

A key issue here is how to optimize network services for various situations based on context. This is especially true for future mobile networks providing abundant services and accommodating heterogeneous access networks. In general, context information is static or dynamic in nature [8], and can be obtained from either the network or mobile terminal. Examples of static context information are the user's profile and application settings and even network location and network functions. Examples of dynamic context information are user location, application requirements, and network traffic.

Another important issue is how to process context information collected from diverse sources into a usable form and then how to distribute it to various mobile terminals while not losing service functionality. This process must also be scalable, i.e., it must be able to accommodate an increase in the number of information sources, mobile terminals, services, and networks.

To deal with these two issues, we have developed a context information management architecture [9] that enables on-demand updating of context-aware network. This architecture is based on a service deployment framework for controlling the provision of network services and on programmable network nodes that enable installing and processing of new network services.

We can offer "context-aware handover" as one example of a context-aware network service using this architecture. In the example shown in **Figure 3**, the wireless access network consists of multiple access points and the user is moving in a region where those areas overlap. Without context awareness, the new access point will be selected only based on signal strength. By using appropriate context information, however, the terminal can request a handover to the most optimal access point for the current context. If the user is riding on a train, for example, it might be best to make a handover to an access point near the train tracks. At this time, the mobile terminal and context collection point exchange context information applicable to a context-aware handover. In such a scenario, context information and the modules that process that information may change frequently. If new context information is obtained, the corresponding processing modules should also be updated on demand. To this end, the programmable network nodes shown in the figure include programmable platforms [10], and a handover support module for exchanging customized context information is placed in the programmable platforms of nodes on both the terminal and network sides. The mobile terminal also uses a module for making handover decisions. These modules can be updated by the Service Deployment Server (SDS).

We have extended this architecture to include the framework for generic context-information management. It can therefore handle generic context information independent of the application while also using context information optimized for a specific purpose and a special mechanism for exchanging that information so that network services can be customized.

As shown in **Figure 4**, the framework for context-information management consists of two types of elements. The first is a general-purpose type of element such as the Generic Context Collection Point (GCCP) and the SDS applicable to any service. The second is an application-specific type of element such as the Context Service Adapter (CSA) and the Context Service Adapter Client (CSAC) that are delivered by the SDS to programmable network nodes or mobile terminals. Each GCCP collects context information from context-information providers and exchanges that information with other GCCPs. A GCCP also delivers the generic context information it has collected to individual applications. At this time, the information must be converted by the CSA to a format that the application in question can understand and delivered to the CSAC by a protocol suitable to that application. In the case of a context-aware handover, the CSA and CSAC would correspond to the handover support module in Fig.3.

An actual implementation of a context-aware handover [11] has demonstrated that the developed architecture is capable of

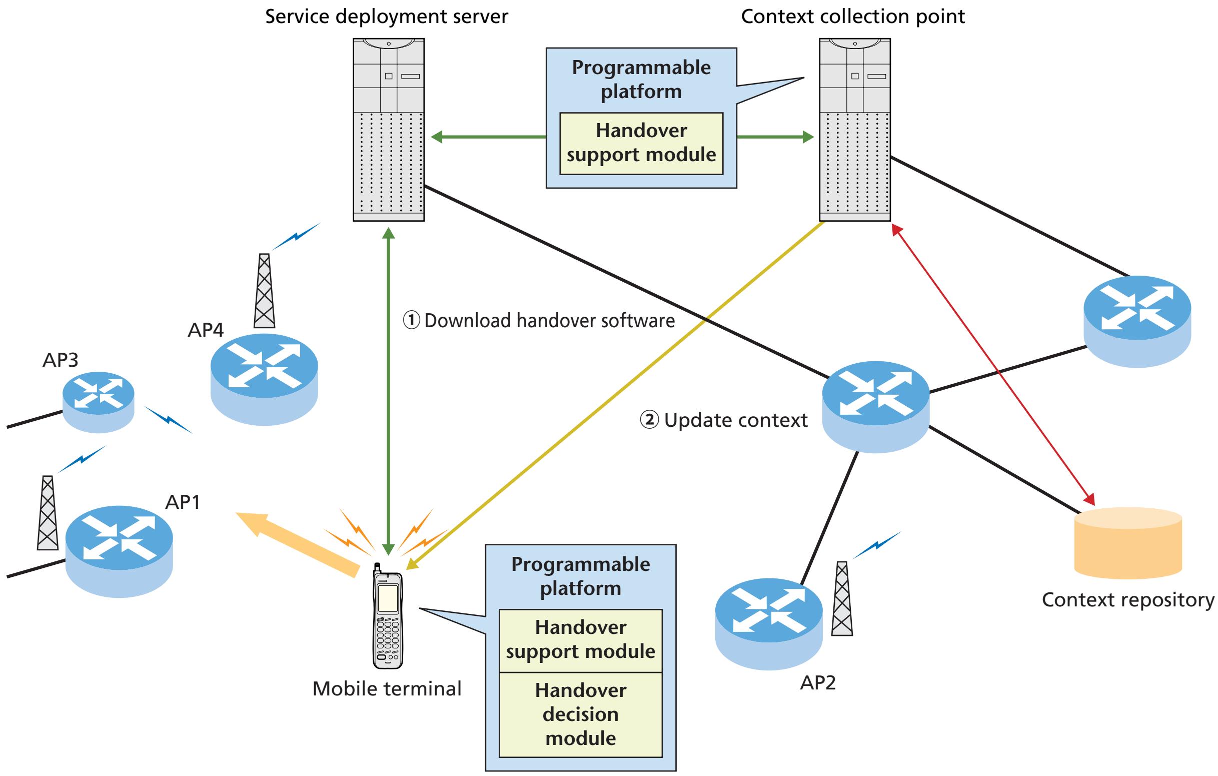

Figure 3 Context-aware handover scenario using programmable nodes

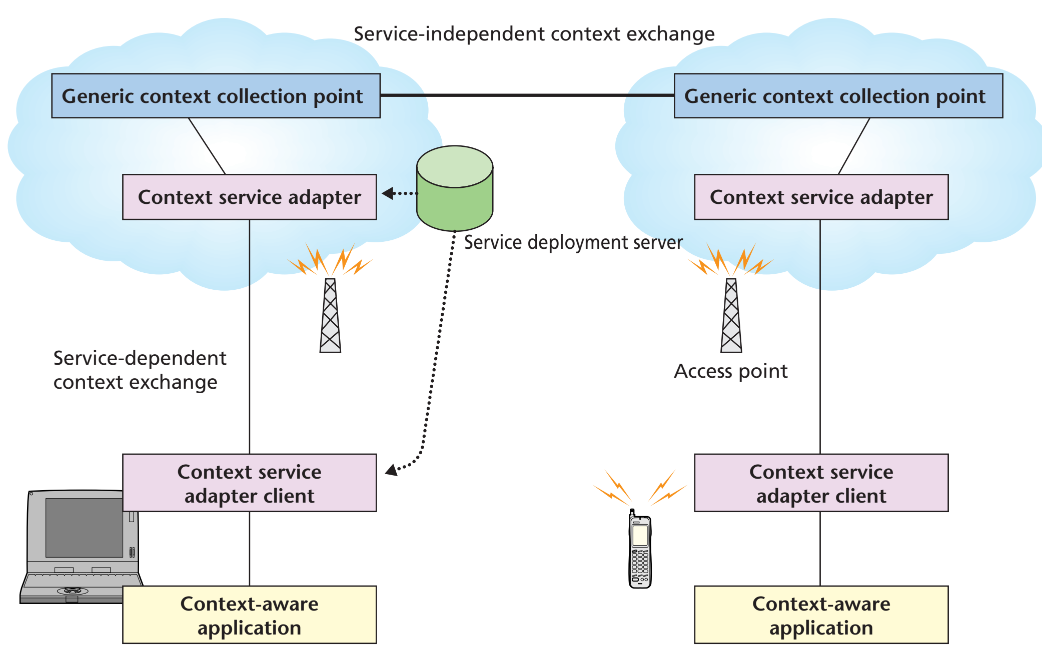

Figure 4 Context management architecture in mobile networks

handling various types of context information and context service adapters. It has also shown that the performance of network services like handover can be enhanced without degrading the performance of the overall network. Furthermore, the use of customized modules is efficient, even though it creates some initial deployment overhead [11].

4. Self-organizing Ad hoc Networks

In an ad hoc network, mobile devices form a self-organizing wireless network. An outstanding feature of an ad hoc network is multi-hop communication. If two mobile devices cannot set up a direct wireless link, other mobile devices located between them can act as relays and transmit data. This capability suggests various types of applications such as autonomous personal area networks, inter-vehicle networks for notification of accidents, and environmental sensor networks. Mobile carriers can use technologies developed for ad hoc networks to design a multi-hop wireless access network as shown in **Figure 5**. In such a network, a mobile device that cannot establish a direct wireless link with an access point may nevertheless use other mobile devices as relays to access the Internet. An ad hoc network can be thought of as a means of extending the service area of a mobile network in a flexible manner and of achieving a wider service area with fewer access points. Interconnection between an ad hoc network and the mobile network does, however, raise several issues in relation to the network layer as summarized below.

- Gateway discovery and selection

  If a device in an ad hoc network wants to access the Internet, it must first discover a nearby access point. The ad hoc network can then connect to the Internet from that access point via a gateway that can handle routing protocols for both the ad hoc network and the Internet. Gateways may be discovered by either a proactive or reactive technique. In the proactive technique, all gateways periodically broadcast messages to all nodes in the ad hoc network. In the reactive technique, a mobile device sends a request message to multiple gateways. If the mobile device should then discover that multiple gateway candidates exist, it must select one of them. An optimal gateway selection method for this situation is a topic for current research.

- Address autoconfiguration

  A mobile device that wants to communicate with nodes in the Internet must be assigned a globally routable IP address. This is enabled by extending the stateless address autoconfiguration function of the Internet Protocol version 6 (IPv6). First, an initial IP address is created to enable the mobile device to communicate with other mobile devices in that ad hoc network. Next, using this address, the mobile device obtains an IP subnet prefix of its current gateway [12]. A globally unique IP address can then be formed using this prefix. With this address setting scheme, all mobile devices connected to the same gateway form one subnet. The issue that arises here is how to handle the above IP address in conjunction with mobility management.

- Integrated routing

  Once a mobile device has registered its IP address with the network, it can exchange packets with nodes in the

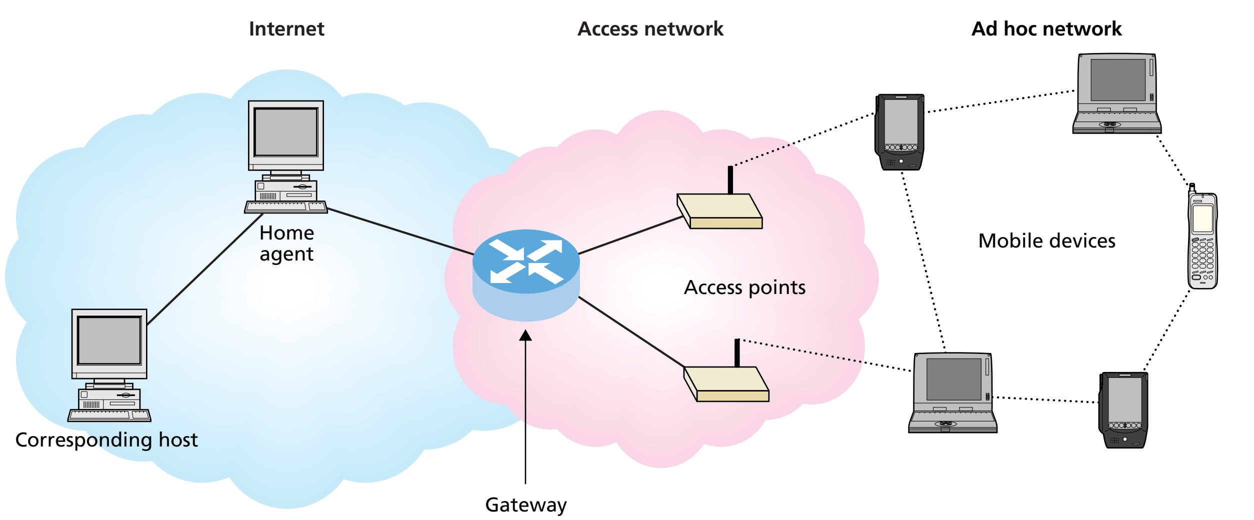

Figure 5 Ad hoc networking and multi-hop wireless Internet access

Internet. When communicating with a mobile device, a node in the Internet sends packets to the home address of that mobile device. The packets are then forwarded to the gateway in question, which then forwards them to the mobile device using ad hoc routing (such as Ad hoc On-demand Distance Vector (AODV) [13]). This scheme can be applied only for mobile devices having low mobility. Enhancing the function to handle high-mobility situations is an issue for further study.

Two interesting problems can be considered here in relation to the above. First, when two mobile devices in the same ad hoc network are connected to different access points or are located in different subnets, which path should they use to communicate with each other: a direct wireless link within the ad hoc network or a path that passes through those access points? Second, how should a multi-hop handover between two gateways be performed [14]? In our research, we have performed several simulations in regard to the above [15].

We have also participated in the Internet Research Task Force (IRTF) working group on Ad hoc Network Systems Research (ANS) [16], and have proposed billing and accounting systems for multi-hop access networks [17].

In addition to problems associated with the network layer, our research is also concerned with media-access control protocols and resource-reservation schemes. We are working, in particular, on a self-organizing resource-reservation scheme based on IEEE 802.11 protocol [18].

5. Conclusion

This article presented the results and current state of research on network-platform technologies at DoCoMo Euro-Labs with particular attention paid to end-to-end QoS, active and context-aware networks, and self-organizing ad hoc networks.

We aim to develop future mobile communication networks and to participate in the 6th European Framework Program to perform joint research with many other major vendors and mobile carriers. We are currently participating in the Ambient Networks project that relates to QoS research [19] and in the End-to-End Reconfigurability (E2R) project that relates to programmable-networks research [20]. The former project studies future architectures based on the concept of "composing networks" that can include enterprise LANs and personal area networks in addition to mobile networks. Establishing E2E service agreement is a key issue in the future research. The latter project studies protocol stacks associated with reconfiguration in relation to reconfigurable mobile terminals.

In research of self-organizing networks, we also plan to take up sensor networks and various future devices such as intelligent devices. This will help accelerate research on context-aware active networks. Above all, we aim to expand the framework for managing context information.

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ABBREVIATIONS

AODV: Ad hoc On-demand Distance Vector
AP: Access Point
CSA: Context Service Adapter
CSAG: Context Service Adapter Client
Diffserv: Differentiated Services
DRM: Domain Resource Manager
E2E: End-to-End
GCCP: Generic Context Collection Point
IEEE: Institute of Electrical and Electronics Engineers
IntServ: Integrated Services
IP: Internet Protocol
IPv6: Internet Protocol version 6
IRTF: Internet Research Task Force
NSIS: Next Steps in Signaling
QoS: Quality of Service
RSVP: resource ReSerVation Protocol
SDS: Service Deployment Server
WLAN: Wireless Local Area Network