

# Hybrid Seamless Mobility Supporting Pervasive Service Collaboration

Dominic Greenwood  
Whitestein Technologies AG  
Pestalozzistrasse 24  
8032 Zürich, Switzerland  
Email: dgr@whitestein.com

Roberto Ghizzioli  
Whitestein Technologies AG  
Pestalozzistrasse 24  
8032 Zürich, Switzerland  
Email: rgh@whitestein.com

Monique Calisti  
Whitestein Technologies AG  
Pestalozzistrasse 24  
8032 Zürich, Switzerland  
Email: mca@whitestein.com

**Abstract**—This paper discusses an approach to seamless hybrid connectivity bridging infrastructure-centric and ad-hoc networks to autonomically maximize the potential for sustained connectivity for terminal device users and their services. The architecture and functional attributes of a Hybrid Connectivity Manager are described, and illustrated through deployment in an incident scenario where rescue workers require seamless hybrid connectivity to support sustained collaboration. The HCM extends an existing technology, the Living Systems Connection Agent for seamless vertical handover between infrastructure networks, with support for ad-hoc connections, and employs a policy-based logic engine a software-agent autonomic controller.

## I. INTRODUCTION

Next Generation Networking (NGN) consists of IP packet-based network deployments capable of providing telecommunications services across multiple broadband, QoS-enabled transport technologies wherein service-related functions are explicitly separate from underlying transport-related technologies. NGN also intrinsically supports mobile users with the ability to communicate and access ubiquitous services irrespective of changes in location, terminal device or access connection. By virtue of these characteristics NGN allows myriad service providers to offer their services to users across multiple connection types.

Due to this delineated design and support for multiple service providers, within emerging NGN deployments such as British Telecoms 21CN initiative [15] [14] the global provisioning of pervasive telecommunications services is becoming rapidly suffused with user-driven content and third-party services accessible across multiple, seamless access technologies. Seamless access is of significant value to users as it transparently converges multiple wireless communications technologies through uninterrupted vertical-handover between the various access connections available to a user device according to connection availability, user preferences, operator and service provider policies. Mobile-IP based technologies such as the Living Systems Connection Agent [5] provide seamless connectivity in accordance with the emerging IEEE 802.21 standard [16] [17] [14]. Session continuity is assured as connections transition across access technologies allowing client devices to maintain the same IP address for an entire session and applications to run uninterrupted.

To date, state-of-the-art seamless vertical-handover, defined by the IEEE 802.21 standard as Media independent handover (MIH), most typically supports handover between infrastructure-centric access connections such as cellular, wireless LAN and WiMAX networks. Our approach extends this model to support Social Area Networks (SANs) through geographically localised ad-hoc connections over technologies such as Bluetooth, ad-hoc wireless LAN, and infrared, etc. This hybrid network [11] [4] is a substrate allowing end-to-end connections between terminal devices that may consist of multiple connection segments seamlessly transitioned across infrastructure and ad-hoc network technologies.

Over this hybrid network substrate resides the service provisioning domain wherein conventional operator-provisioned services are accompanied by passive content and active services contributed by so-called prosumers [18] and third-party provider services. These services, which may also draw on passive content resources, can collaborate across the potentially changing underlying network landscape by virtue of seamless handover technology to form short or long lived composite service assemblies. While such collaborations may draw on widely dispersed services and content, of particular interest is the ad-hoc seamless mobility extension discussed in the following sections which allows content and services located, and perhaps generated by, diverse prosumer terminal devices to collaborate within geographically constrained Social Area Networks that span devices present within the range of ad-hoc technologies such as Bluetooth and ad-hoc wireless LAN.

Such composite assemblies of services result from localised collaboration as appropriate to scenarios such as the emergency worker coordination case outlined in Section V, or more generally, cases where prosumers choose to collaborate with one another by generating and sharing services and content in a common location. In all cases while users may choose to take advantage of access to other locally located terminal devices to collaborate via short-range ad-hoc technologies, they will nevertheless remain connected via seamless connectivity to available infrastructure networks. This implies that service composite assemblies may, and will, be constructed from services drawn from both local and remote sources dependent on application context; in fact such assemblies may change both their constituents and the means of communicating with

those constituents dynamically and in real-time.

Creating content, combining it into short-lived, ad-hoc composites with other diverse content types, and seamlessly provisioning it over multiple access technologies is a central component of the Telco 2.0 vision, substantially informed by operator network convergence strategies and the user-driven content revolution of Web 2.0. This paper proposes a technology substrate for offering seamless connectivity for client device users across a hybrid of standard infrastructure networks (cellular and wireless) and ad-hoc peer-to-peer networks (bluetooth, wireless ad-hoc, etc.).

The following section discusses some relevant published work. Section III presents the architecture of a proposed Hybrid Connection Manager (HCM). Section IV then describes the connection and usage aware connectivity management features of the HCM and section V illustrates a real-life scenario within which the HCM prototype has been evaluated.

## II. RELATED WORK

Among published works dealing with hybrid networks consisting of a combined infrastructure and mobile ad-hoc connectivity, only a few then consider either the requirements and influence of the user applications running over the autonomic communications subsystem, or the roles of end-users in deployment scenarios.

An example of hybrid network management is provided in Hauge *et al.* [11] who discuss an approach to the combined use of 3G cellular and ad-hoc networks. The authors conclude that hybrid networks provide the opportunity to transmit service data to a higher percentage of interested mobile terminals than when using only an infrastructure network. Nevertheless, the role of their user-level service (multicast) within hybrid networks is not considered. The same can be said of the work of the *Delay Tolerant Networking Research Group* [1] chartered as part of the Internet Research Task Force (IRTF). This group focuses on network aspects providing end-to-end connectivity in disruptive environments without considering how application contexts influence the achievement of connection/delivery goals. We address this issue as a component of the HCM usage-aware approach (see section IV).

Another important work in this area is that of Kappler *et al.* [12] who use a policy-engine to address hybrid network composition. Although this aspect is in line with our approach, the authors do not consider the discovery of relevant network nodes, and policies are only used for the composition of network devices, whereas our approach also considers the possibility of user-level service composition.

The notion of Unified Messaging (UM), as reported in van der Meer *et al.* [13] for example, is also closely related to our work from the perspective of supporting both fixed and mobile users with universal access to communication services. The central concept of UM is the capability of the messaging system to select the most appropriate terminal or application for an incoming message according to availability, status, and other parameters. A UM system is designed to adapt terminals to different kinds of services via content adaptation

processes guided by user rule policies. However, the particular approach documented in [13] identifies CORBA as a suitable means of engineering the middleware software for handling UM; an approach, in our opinion, not entirely suitable for application in pervasive environments where seamless mobility is a paramount issue and small footprint devices are the norm, as is particularly the case in disruptive environments.

Additionally, published work relating to the use of ambient and pervasive technologies in disruptive environments or disaster management tends to focus more on service composition or other application-oriented aspects without considering the underlying networks issues. Such an example is the reported work of Kristensen *et al.* [6] which focuses on IT support in major incidents, such as the use of bio-monitors, patient identification and collaboration tools for response units, without considering how these applications could, or should, behave in the presence of network disruptions. The HCM system reduces this gap between specific autonomic aspects purely based on the network management and the autonomic aspects based on the user-level services deployed in disruptive environments.

## III. ARCHITECTURE OF THE HYBRID CONNECTION MANAGER

The Hybrid Connection Manager (HCM) is terminal device logic extending an existing seamless mobility technology known as the Living Systems Connection Agent (LS/CA) [5] which enables vertical-handover between Wireless LAN and Cellular technologies (i.e., GPRS, UMTS, HSPA). The LS/CA is based on Mobile IP technology which offers session continuity by allowing a client to maintain the same IP address for an entire session and applications to thus run uninterrupted. The HCM extends the LS/CA with support for seamless handover between ad-hoc networks including Bluetooth, ad-hoc Wireless LAN and IrDA. The result is seamless connectivity across any available combination of hybrid infrastructure and ad-hoc networks. Both the original LS/CA and the HCM extension automatically detect available networks, with support for new technologies added via a plug-in architecture.

The HCM mirrors the LS/CA in being designed as an autonomic system that shifts selected configuration tasks from users to a specialised self-regulating subsystem. A local policy engine is used by each HCM deployment for auto-configuration purposes, allowing autonomic adjustment of behaviour in accordance with environmental changes. The HCM is also capable of auto-optimization by monitoring network resources and adapting its behaviour to meet end-user and application service connectivity requirements, i.e., automatically handing-over sustained sessions between different access connections when a connection failures occur, or to simply maximise the goal of remaining connected to the best<sup>1</sup> available connection.

The HCM software architecture is depicted in Figure 1 and consists of an autonomic manager and several managed elements: an user application interface service, a network bearer

<sup>1</sup>A 'best' connection may be considered to be that with the optimal QoS criteria

interface service and policy service. The autonomic manager uses a policy engine decision logic to control seamless handover by responding to network events, application events in accordance with dynamically configurable policies. Policies are used to guide the autonomic decisions that the HCM autonomic controller can take in response to events sensed from the environment. A simple example is the detected failure of an infrastructure connection (say WLAN); a predefined obligation policy mandates that the HCM re-route<sup>2</sup> messages via one or more alternative network technologies to either their final destination or another node with an active infrastructure connection. An example of such a policy is described in Section V.

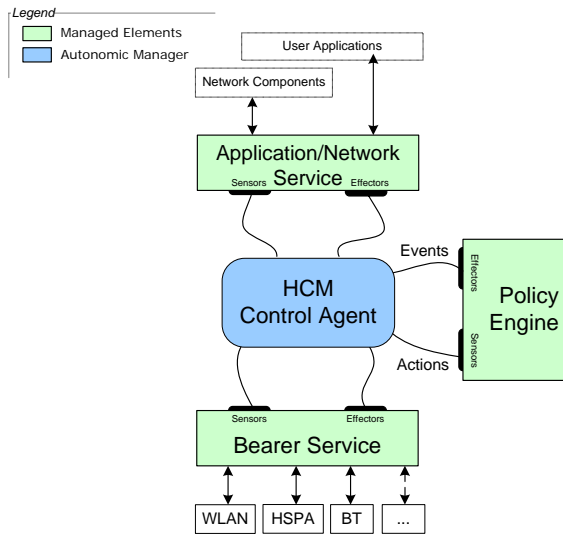


Fig. 1. HCM software architecture.

The HCM software is designed to interact with different layers of the user-device communication stack. In the default case it interacts with lower-layer communications components dealing with bearer technologies, e.g., UDP, Bluetooth, etc., and with upper-layer components dealing with, for example, routing protocols, discovery, and services/applications. Other components may also interface to the HCM through provided software interfaces.

A prototype of the HCM has been created using the JADE [2] (Java Agent DEvelopment framework) multi-agent system development and runtime environment. As JADE<sup>3</sup> supports J2ME and MIDP it was an ideal candidate for initial fast-prototyping work. The HCM autonomic manager is designed for deployment as a JADE agent and the managed element interfaces are deployed as JADE kernel services, both of which are executable within the JADE runtime.

#### A. The Managed Elements

The HCM control agent interacts with the external world via JADE kernel services. Each service is controlled through

<sup>2</sup>Routing of traffic, especially over ad-hoc connections, is considered beyond the scope of this paper

<sup>3</sup>JADE documentation and software is available from <http://jade.tilab.com/>

sensors and effectors. Effectors produce actions relating to instructions received from the HCM agent; they implement the *Command* design pattern [7]. Sensors collect information from the external world and provide it to the agent for processing; they implement a simplified version of the *Half-Sync/Half-Async* design pattern [3]. The HCM has three JADE kernel services:

*The Network/Application Service* is used by the HCM agent to interact with upper-layer network services, such as routing and discovery, and application services facing the user. Messages passing through this interface may be inspected by the HCM to determine whether any action is necessary by the autonomic manager in accordance with specified policies. A selection of interfaces are available allowing communication with a broad range of network services and applications.

*The Bearer Service* is used by the HCM agent to interact with the lower-layer bearer interfaces to both infrastructure and ad-hoc network endpoints. Messages passing through this interface may be inspected by HCM to determine whether any action is necessary by the autonomic manager in accordance with specified policies. A selection of interfaces are available for a broad range of network technologies.

*The Policy Service* is used by the HCM agent to interact with the local policy engine (see Section III-C). In brief, this engine possesses the operational rules that must be applied to control (or not control) the way in which messages are treated by the HCM. The HCM agent uses these policy rules to effect this control.

#### B. The Autonomic Manager

This is the software agent that controls the HCM system such that it exhibits the following autonomic behaviours:

*Sensing:* By installing sensors in the managed elements the agent is able to monitor new application messages to be sent, new messages received from the network or new network status events. Data is collected both asynchronously (the managed elements notify of a status changing) or synchronously (the agent explicitly request for information).

*Compiling Knowledge:* Intercepted messages and received events are used to create an internalized model of the external world. This compiled knowledge base contains information such as statistical flow data, historical fault logs, active and treated faults, discovered devices and the services those devices provide.

*Decision Control:* Whenever the internal knowledge base is updated, the HCM agent triggers a call to the local policy engine which dictates the policy constraints that must guide decision-making by the agent. This aspect is discussed in more detail in Section III-C.

*Proactivity:* Actions can be executed by the HCM agent immediately, or postponed until some point in the future. In order to schedule such future actions the HCM implements a model of time allowing proactive planning.

#### C. Decision Making

A core aspect of the HCM system is its reasoning system. The HCM agent receives messages from user-level applica-

tions and probes the environment using the previously discussed managed element kernel services. Decisions on how to treat the received messages are made locally using *policies*; a set of constraint rules governing system behaviour. One of the goals of the HCM is to provide the end user with an easy means of authoring policies that will control the various autonomic features. In order to modify the HCM behaviour at runtime, these policies are dynamically loaded when the device is running.

Policies are not coded directly within the agent behaviours. To be more flexible, the agent uses the Policy Service managed element, shown in Figure 1, to issue events to a policy engine and wait for a set of recommended actions to perform. The particular policy server employed by the HCM is Ponder2<sup>4</sup> [8] citerussello, used as a local library, which uses an XML-based policy description language to define events and policies to be processed by the Ponder2 policy engine. The result of a policy is an action the HCM agent has to perform. Currently, the HCM deals with *obligation policies*. An obligation policy is an Event Condition Action (ECA) rule in the deontic sense [10]. Given  $E$ , and  $C$  is true, it is obligatory that the agent performs  $A$ .

#### IV. CONNECTION AND USAGE AWARE HYBRID CONNECTIVITY MANAGEMENT

Two of the primary features of the HCM are support for *connection-aware* and *usage-aware* communication.

*Connection-Aware Communication* is the ability of the HCM to remain aware of all available (active and inactive) infrastructure and ad-hoc network connections, their parameterization and performance characteristics (e.g., Quality of Service (QoS) characteristics). This set of autonomic behaviours are triggered by changes in network resources, with some of the most significant operations being:

- **Network handover** : The capability of dynamically switching from one network type to another when communicating with other devices. This decision can be taken based on the reachability of a device over different infrastructure or ad-hoc networks and on network availabilities. For example, we can consider handovers from an infrastructure technology (e.g., supporting UDP connections) to an ad-hoc technology (e.g., supporting Bluetooth connections) when communicating with a device in the local neighbourhood.
- **Routing optimization** : The capability of enhancing multi-hop routing among network nodes. Parameters which affect these decisions can be based on several QoS parameters such as response delay, nominal and available bandwidth between network nodes, transmission errors, etc. For example, a self-optimization feature of the HCM fitting into this group is the proactive evaluation of the transmission delay between two interoperating devices and consequently the use of an alternative path to reach the same target node.

Other behaviours within this category include those acting in response to failovers or high network load, etc.

*Usage-Aware Communication* consists of a set of autonomic behaviours related to the usage of deployed user-level services. For example, a group of rescue workers are on the site of a major accident with human casualties and must constantly maintain communication with both with one another and with a response unit concerning their findings and the positions of injured people. Due to the potentially disruptive nature of the environment network availability may be intermittent, but the goal to reliably deliver communication must persist. In this scenario the typical autonomic decisions to be taken include:

- **Transmission contingency**: The capability of providing alternatives to the default means of transmitting a message. This specifically includes making the best possible use of multi-technology transmission paths including cellular networks, IP infrastructure networks, satellite systems, MANETs, etc. An important parameter in these decisions is the importance of the message to be sent. An example is simultaneously sending high priority messages via two or more different technologies, and therefore routes, to improve the chances that they are successfully delivered to target nodes. The use of extra resources is justified by the importance of the content to deliver.
- **Content adaptation**: Adapting the content of a message (or stream). These decisions can be based on several parameters such as the number and the importance of the messages/streams to be sent. Examples include applying a codec to reduce the bandwidth consumed by a video stream, or simply stripping out the audio component and sending this in lieu of the video.
- **Deferred service provisioning**: Waiting until a connection is available before making routing decisions to mitigate uncertainty relating to the choice of optimal technologies or paths. Also in this case the parameters able to trigger this type of decisions are the volume and the significance of the information to be sent. This includes the need to buffer messages while awaiting a connection.
- **Role management**: Specifying user defined conditions which must be met before taking a particular action. A parameter which affects these decisions is the role of the end-user in a particular scenario. For example within a major incident response workers are divided into response units, structured in a hierarchical manner. In this scenario we can envisage policies which ensure a message (e.g., notification of an event) is sent to the right recipients in the role hierarchy (e.g., escalating).

All of these capabilities are controlled by user-definable policies that may be simply and rapidly specified/modified on-the-fly by either the user or local/remote automated routines.

#### V. CASE EVALUATION

One domain in which the HCM has been demonstrated through experiment to be of considerable value is in supporting collaboration between rescue workers at incident sites [6].

<sup>4</sup>see <http://ponder2.net/>

The various responders to an incident may include police, firefighters, paramedics, coastguards, the military and other specialist teams. Moreover these people often only represent the vanguard of a much larger team of personnel working off-site including logistics support, consultants, administrators, etc. It is critical that communication between all parties involved in an incident remain available at all times, and that different channels of communication be available according to task and location constraints. Personnel working in close proximity at the incident site may share information in a Social Area Network relating to services such as positioning information, map topologies, biometrical data, etc., via ad-hoc connections, perhaps as a preference or in the absence of a reliable infrastructure connection. The critical aspect is the assured preservation of communication even in such potentially disruptive environments. Sessions must be as continuous as possible, providing a consistent experience by seamlessly adapting configuration according to available access technologies, device types and locations.

An early HCM prototype has recently been a key component of experiments involving rescue personnel operating at a major incident site. In one particular experiment a building fire is considered. This particular scenario demands fast and decisive action, often in life-threatening situations. It also requires collaboration between numerous people located in different, often changing areas: personnel at the incident site including fire-fighters, police, and paramedics, at the command center, in vehicles, and others.

Each of the people involved, and many of the vehicles and other equipment, are associated with one or more electronic devices such as radios, biosensors, GPS, health recorders, handhelds, tablet PC, etc. In the fire scenario different devices run different crisis-relevant applications including VOIP clients, instant messengers, map services and other collaborative tools.

This scenario is illustrated by Figure 2. Two Fire-Fighters (FF) are moving in relative proximity to one another attempting to evacuate people from a building on fire. They are using small, wearable HCM activated PDAs and are able to communicate with local CCTV cameras that are broadcasting video streams of the location on several access channels. The duty of the fire-fighters is to explore the incident site and notify the Command Center (CC) and the other local team members of findings related to visited building(s), i.e., the positions of injured people. To do this, they make special marks on the map displayed on their PDA. They may also take pictures using the PDA's in-built camera to assist the command center with gaining a visual overview of the incident location and status.

In terms of connectivity, FF1 and FF2 are connected via both ad-hoc (AH) and infrastructure (IN) networks, and the two CCTV cameras are capable of only broadcasting images over a local ad-hoc connection. In this situation indicated where certain infrastructure connections fail due to some disruption at the incident site, fire-fighters remain able to communicate using their ad-hoc connections while in relative

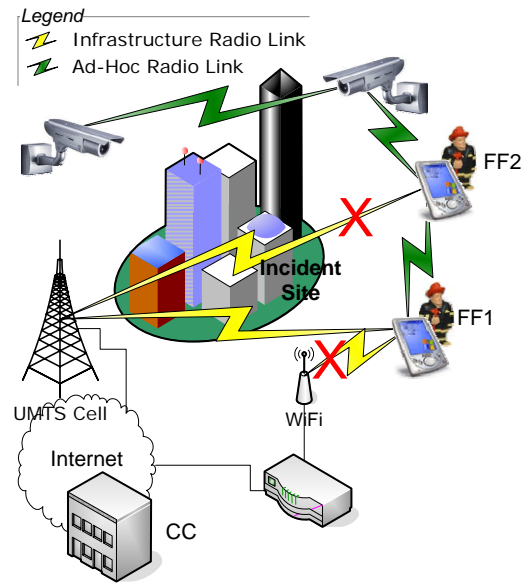


Fig. 2. Rescue worker scenario.

proximity to one another. If an infrastructure connection were to become re-established the HCM may decide, according to prescribed policies, to switch FF2 back to this connection allowing him to communicate directly with the CC rather than via FF1.

In this particular scenario, the firefighter's devices are equipped with the following policies:

- 1) *IF (infrastructure\_connected) THEN send map data to CC and FF via INFR.*
- 2) *IF (!infrastructure\_connected) THEN send map data to CC and FF via HOC.*
- 3) *IF (infrastructure\_connected) THEN send high resolution pictures to CC via INFR.*
- 4) *IF (!infrastructure\_connected) THEN send low resolution pictures to CC via HOC.*

Figure 3 shows the definition of the fourth policy statement in this list. This policy sends low resolution pictures to the command center when the device is not infrastructure connected. It receives media status events which denote whether a network interface is available or not. This event has two associated parameters: the interface protocol and its current status. The only condition that triggers this policy is that the infrastructure connection is unavailable (see the XML *condition* element). The action *sendLowResolutionPicture* triggered by this policy notifies the HCM agent to decrease the resolution of the pictures for the command center and to send them using the ad-hoc network (see the *protocol* attribute of the *sendLowResolutionPicture* XML element).

In this scenario, FF1 has policies (1) and (3) activated. When FF2 moves into an area where the infrastructure connection fails, this is detected and policies (2) and (4) automatically become active. The HCM running on FF2's PDA is thus notified by the policy engine and hands over all communication with FF2 to the available ad-hoc connection with FF1.

```

</use name="/policy">
  <add name="contentAdapt">
    <use name="/template/policy">
      <create type="obligation"
        event="/event/mmstatus" active="true">
        <arg name="alive"/>
        <condition>
          <eq>protocol;datagram</eq>
          <eq>!alive;false</eq>
        </condition>
        <action>
          <use name="/rascalmo">
            <sendLowResolutionPicture
              protocol="bluetooth"/>
          </use>
        </action>
      </create>
    </use>
  </add>
</use>

```

Fig. 3. Policy statement to send low resolution pictures to the command center via the ad-hoc network when the infrastructure connection is no longer available.

Given the importance of sending images to the command center and giving the low nominal bandwidth of the ad-hoc channel, pictures are first automatically reduced in quality (i.e., resolution) before transmission.

Later, when FF2 returns to an area with infrastructure network coverage, communications with the command center are automatically returned to the infrastructure connection with images once again sent in normal, high resolution.

Real world experimentation with emergency services is ongoing with results to be published in a forthcoming paper; a particular focus will be analysing the effectiveness of service collaboration across the seamless hybrid network substrate. We are also assessing a related scenario where clusters of rescue personnel at different sites use the HCM to actively collaborate when coordinating search and rescue activities.

## VI. CONCLUSION

This paper has provided an introduction to a Hybrid Connection Manager technology based on autonomic communications software components designed to manage seamless connectivity across infrastructure and ad-hoc networks. The HCM can be interfaced with device communication stacks and offers features including automated network handover, routing optimization, transmission contingency, content adaptation, deferred service provisioning and role management. The key components of each local HCM deployment are a software agent autonomic control logic and a policy engine with which the user is able to define rules guiding and constraining the policy-driven agent control logic.

The HCM is an early prototype technology extending an existing product, the Living Systems Connection Agent - winner of the 2005 GSMA award for best mobile enterprise application through its incarnation as Swisscom's Unlimited Data Manager<sup>5</sup>. Particular ongoing work includes areas that enhance the autonomic capabilities of the system including

the incorporation of improvements to the policy expression language, and to the autonomic controller logic. The improvements to the policy language include a new means of expression using a form of process-algebra over actions. This allows the expression of a set of actions (i.e., workflow) rather than the current limitation to atomic actions. Further planned improvements relate to the inspectability of the HCM system and its use in composing dynamic assemblies of computational devices and services with flexible, self-adaptive communicative connections.

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<sup>5</sup>See <http://www.whitestein.com/library>