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Cloud Services in Mobile Environments

The IU-ATC UK-India Mobile Cloud Proxy Function

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***Abstract*—Mobile networks currently play a key role in the evolution of the Internet due to exponential increase in demand for Internet-enabled mobile devices and applications. This has led to various demands to re-think basic designs of the current Internet architecture, investigating new and innovative ways in which key functionalities such as end-to-end connectivity, mobility, security, cloud services and future requirements can be added to its foundational core design. In this paper, we investigate, propose and design a functional element, known as the mobile cloud proxy, that enables the seamless integration and extension of core cloud services on the public Internet into mobile networks. The mobile cloud proxy function addresses current limitations in the deployment of cloud services in mobile networks tackling limitations such as dynamic resource allocation, transport protocols, application caching and security. This is achieved by leveraging advances in software-defined radios (SDRs) and networks (SDNs) to dynamically interface key functions within the mobile and Internet domains. We also present some early benchmarking results that feed into the development of the mobile cloud proxy to enable efficient use of resources for cloud based services such as social TV and crop imaging in mobile environments. The benchmarking experiments were carried out within the IU-ATC India-UK research project over a live international testbed which spans across a number of universities in the UK and India.**

***Index Terms*—Mobile, cloud, LTE, cloud proxy, social TV.**

I. Introduction

The Internet has evolved from a network initially designed for basic end-to-end connectivity to a critical global platform used in healthcare, governments and enterprises to mention a few. Supporting the current scale of the Internet has required various tweaks that were not considered during its initial design and have been added along the way. These have made the Internet more complex to manage, stagnant of innovation and most importantly, breaking up the initial concept of end-to-end connectivity between communicating end hosts [1].

Nowadays, with the exponential rise in demand for mobile Internet due to its social, political and economical advantages, mobile networks and end-devices that were initially developed to carry mainly voice traffic have evolved to carry high-speed Internet traffic. The mobile networks have gone through various phases – 2G, 2.5G, 3G, 3.5G and 4G – using different architectures and protocols in order to cope with the increasing demand for mobile Internet. In most recent 4G mobile infrastructures, the mobile network is designed as a native extension to the public Internet using an all-IP network to allow seamless interconnectivity between the Internet and mobile networks while also using standardised Internet protocols [2]. However, some critical functionalities needed in mobile networks such as resource management, mobility (transport & security) and AAA (Authentication. Authorisation and Accounting) that were not considered during the initial design of the Internet and have only been added as extensions (IPSec, Mobile IP, RADIUS, etc.) still poses as challenges to the seamless integration of mobile networks and the public Internet. These limitations has led to various demands to re-think the basic designs of the current Internet architecture, investigating new and innovative ways in which key functionalities such as end-to-end connectivity, mobility, security, cloud services and future requirements can be added to its foundational core design.

In this paper, we investigate, propose and design a functional element known as the mobile cloud proxy that enables the seamless integration and extension or core cloud services on the public Internet into mobile networks. The mobile cloud proxy function addresses current limitations in the deployment of cloud services in mobile networks tackling limitations such as dynamic resource allocation, transport protocols, application caching and security. This is achieved by leveraging on the advances in software-defined radios (SDRs) and networks (SDNs) to dynamically interface key functions within the mobile and public Internet domains. We also present some early benchmarking results that feeds into the development of the mobile cloud proxy in order to enable the efficient use of resources for cloud based services such as social TV and crop imaging in mobile environments. The benchmarking experiments were carried out within the IUATC UK-India project over a real global testbed spanning between a number of universities in UK and India.

Furthermore, in this paper, Section II provides an overview on the challenges of deploying cloud services in mobile environments with a focus on current research works in dynamic resource allocation, transport protocols, application caching and security aimed at addressing these limitations. In Section III, we provide the requirements and specifications for the design of the mobile cloud proxy while looking at key characteristics such as latency, load, caching and charging to mention a few. In Section IV, we provide an overview of the IUATC UK-India global testbed interconnecting research platforms at universities and research organisations in the UK and India with the aim of providing a global platform for early and rapid prototyping of new technologies. We then provide the results of the initial benchmarking experiments of the mobile cloud proxy on the IUATC UK-India testbed using two resource intensive applications – mobile social TV and crop imaging cloud services. The initial benchmarking results provides a baseline for the expected improvements from the deployment of the mobile cloud proxy. For example the mobile cloud proxy is aimed at reducing application response times between Mandi, India to Ulster, Ireland that is currently above 200ms and not acceptable for the crop imaging application. More details on the experiments and results are provided in Section IV. Finally in Section V, we provide our conclusions and future outcomes.

II. Challenges of Cloud Services in Mobile Environment

Although cloud based services have been available for a while, however, their current evolution stems from the generation of new business models based on the elasticity and scalability of Internet based infrastructures. This approach allows application providers to dynamically demand resources as needed which in return provides savings on costs, energy, management to mention a few. Although this approach has so far been successfully deployed over the Internet for a wide range of services, in mobile environments, there are still a number of limitations that affects the delivery of cloud based services. Although there is an exhaustive list of these limitations [3], in this paper we focus on the four key areas described below as they closely affect the deployment of the cloud based services of interest to us – mobile social TV and crop imaging – in mobile environments.

A. Dynamic Resource Allocation in Mobile Environments

Efficient allocation of resources in mobile environments has always been a challenge that has been addressed by well-known algorithms [4]. Historically, resource scheduling has been achieved by responding to application performance objectives through balancing workload across resources, responding to requests fairly in the order in which they arrive, and dealing with those that may be serviced most quickly. Typically, resources are provisioned in a volume considered sufficient in relation to the demand typically placed on them. Such approaches to accessing network services however, have varying efficiency levels in mobile environments, particularly when measured in relation to next generation network issues, such as the most efficient path to route traffic, physical resource sharing at a base station, maximum volume of requests, the frequency with which requests are made and the management overhead to allocate resources dynamically. This is further complicated by external factors that are subjective and difficult to quantify, particularly with regard to end-user Quality of Experience (QoE) [5]. However these subjective factors play key roles in the measurement of service delivery and user experience in both cloud and mobile environments.

However as web and cloud applications are increasingly being accessed via mobile networks, the mobile access network still poses as a bottleneck in the end-to-end dynamic resource management as there are currently no ways to dynamically provision mobile resources such as the frequency spectrum, quality of service and radio access bandwidth. One of the main advantages of cloud services has been the ability to provide a programmable platform that allows web applications to easily scale as needed. The scalability is achieved by dynamically provisioning resources such as computing, storage and network. At the moment, it is a challenge to dynamically provisions and allocating resources within mobile environments, as it is dependent on a number of different factors.

B. Cloud Aware Transport Protocols and Adaptiation

Another key limitation in accessing is the need to assess the end-to-end characteristics of transport protocols with various options for cache/proxy placement. This is because the proposals for dynamically provisioning end-to-end delivery path in mobile environments, including the integration of smart proxy systems to allow caching, transcoding and transformation have not been fully proven with no real life deployments [6]. Although these approaches are proven to be effective over the Internet with the use of Content Delivery Networks (CDNs), the cache/proxy placement itself could be a cost-benefit trade-off in mobile environments – i.e. A close proximity to clients will in return limit the centralization, aggregation or consolidation of resources, but may mean better service delivery. Transport protocols and applications will need to be dynamically adaptable to mobile environments in order to efficiently utilize mobile resources in return saving costs and energy.

C. Application Caching

Over the recent years, video traffic has increased exponentially especially within mobile networks. However, most of the video traffic originates from the Internet into the mobile network using Internet based cloud services with limited details on the mobile environment. The key limitation of such a unidirectional setup includes but are not limited to; efficient caching at points along the route; transport protocols for efficient delivery; and flow of control information between the caching servers and the video repository [7]. All these limitations will require resource and energy efficient approaches in addressing them. Although, a better approach could involve the streaming of video in which the video is not downloaded fully, but is played out while parts of the content are being received and decoded. However, in order to achieve video streaming at an acceptable quality, there are strict bandwidth, latency and delay requirements that need to be achieved. It is also important to note these requirements are dramatically high in mobile environments due to various mobile conditions, especially when the media servers are hosted in separate geographic locations. These unacceptable parameters in return degrade the user experience [5].

D. Security and Resilience in Clouds

Security and resilience limitations already do exist on Internet based cloud services is due to the highly distributed and dynamic nature of cloud computing [8]. However, the resilience aspects have so far not been sufficiently explored. The main areas includes how threats can be detected, how anomalies and new threats can develop within a cloud environment and which new threat vectors are introduced through cloud services, and what structural and functional provisions have to be made in order to protect cloud operations and make the entire infrastructure more resilience. It is important to note that these limitations will also be experienced in mobile environments as they even more prone to security attacks and failures due to factors such as mobility, air-interfaces and non-IP based security protocols. In order to address these limitations there need to be an approach to provide more robust traffic analysis and anomaly detection, through an integrated multi-level network resilience framework for end-to-end monitoring of all forms of threats. This has to be combined with mechanisms and algorithms operating in a coordinated fashion both in the edge and in the core networks. Additionally, cyber-security in the Cloud must address emerging vulnerabilities associated with the characteristics of such environments, including the collocation of computation and confidential data of multiple users (multi-tenancy), exploits in virtualisation technologies, and processing elasticity. Also, more traditional security threats are expected to take new forms in Clouds, including abuse of resources, malicious insiders, malware propagations, and account hijacking.

III. The Mobile Cloud Proxy Function (MCPF)

Based on the limitations highlighted in Section II, the aim of the Mobile Cloud Proxy function is provide a dynamic and programmable interface that easily integrates the mobile and public internet domains in order to allow for the deployment of cloud based services in mobile environments. In this section we provide the requirements and specifications that influenced the design of the Mobile Cloud Proxy Function.

A. Requirements for the Mobile Cloud Proxy Function

One key requirement in the proposals for the MCPF is the ability to identify the resource footprint of cloud based applications such as the social TV and crop imaging due to their competing resource requirements. Furthermore, another requirement is to identify user behaviour and explore its predictability. Together, these allow estimations of service demand and resource requirements that may be used to influence the proposed design for the MCPF. This is important because the MCPF must have the ability to carrying out cloud management functionalities so as to make key decisions such as the placement of datastore(s), replication of files across datastores, placement of management proxy, size of the cloud, and characteristics of server resources deployed (such as disk, memory and CPU size) need to the cloud service to be functional in a cloud environment. In simpler terms, the MCPF servers as a broker on behalf of remote resources, which are not part of a centralised data centre or mobile network, with the function of offering, part or all of the needed resources- i.e. compute, storage and network resources to an application. Traffic from the mobile environment aimed at cloud services on the Internet is intercepted by the MCPF in order to dynamically provision the resources needed for the particular cloud service session.

Although there exist well-established interfaces and protocols to integrate the mobile and fixed environments, the MCPF will provide an aggregation point that will allow the dynamic and programmatic invocation of these interfaces and protocols as discussed in the specification in the next section.

B. Mobile Cloud Proxy Function Specifications

As there already exist a wide range of cloud service providers with varying contractual arrangements with different Mobile Network operators (MNO), the MCPF will allow for mobile network operators to federate all managed cloud based services aimed for their mobile network while abiding to varying needs and SLAs of different cloud services providers. In order to achieve this, the specifications below need to be considered

1. **Reduced Network Latency**: It is assumed that the MCPF will be at a closer network proximity, to a set of users, than the central data centre (i.e. a lower packet latency is expected). It is expected that the user should be presented with feedback from the proxy-based application in a shorter time frame than would be the case from the central-based application.
2. **Reduced Load on Metro and Core Networks**: The load on the metro and core network, between the MCPF and the central data centre, will be reduced because the user request is processed at the edge. It is expected that this reduction will reduce the risk of bandwidth and I/O contention at the central data centre, especially at times of heavy load. This reduces the need for dedicated high capacity transmission mobile backhaul networks [9].
3. **Reduced Compute Load at Central Data Centre**: The load at the central-based application, and its assigned resources, should be reduced because the MCPF is processing part or all of the user requests. It is important to note that the placement of the MCPF is dependent on the operator's network design as multiple and redundant MCPFs can be use.
4. **Application Resilience:** A proxy-based application should continue to offer a service, in part or in full, to the user in the situation where connectivity to the

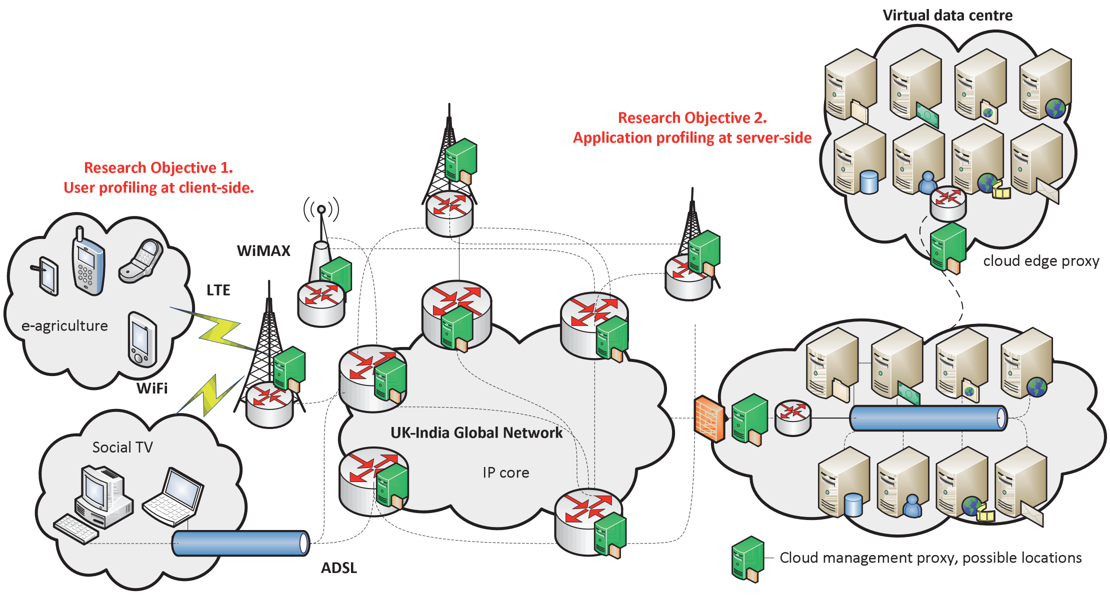

Fig. 1. The IU-ATC UK-India Global testbed

central data centre is lost. This resilience can ensure that critical applications are always available.

5. **Adaptive Resources**: A user might demand resources in different qualities based on his preferences or bandwidth availability. For example, an end-user can have access to various qualities of video.
6. **Access Control**: Access control enforcement on the cached copies of resources in different administrative domains based on factors like payment, age, device, location of access.
7. **Cache design**: This should factor-in the following concerns load of transcoding, user skipping ahead in the video being streamed live and storage for full video caching.
8. **Charging model**: As the MCPF will provide additional advantages, a charging model needs to be developed putting into consideration payment distribution between the cloud services provider and the mobile operator [10].

C. Mobile Cloud Proxy Function Design

The cloud proxy is designed to provide benefits over existing cloud infrastructures. A means of assessing these benefits is required in order to justify the rationale for implementing one or more cloud proxies. To achieve this we compare the cloud proxy topology with traditional Internet client/server topology, and current hybrid cloud topologies [11].

As shown in Fig. 2, the applications deployed using the Mobile Cloud Proxy Function (MCPF) are the selected Social TV and a Crop Imaging classifier. The MCPF is designed to provide the following two key functionalities. At the application level, the proxy decides whether or not user requests are passed to the application or forwarded to the application at the central data centre. This decision is influenced by the proxy's second function, which is to monitor cloud resources (box 3 Fig. 2), and to check that the available resources are sufficient to deliver the application. If the resources are insufficient then the proxy bypasses the local application and forwards the load to the central data centre. If, over a pre-defined period, the application is repeatedly starved of a particular resource, then the proxy can request, from the cloud management solution, to increase the amount of that resource to be allocated to the application's VM. Similarly, if the proxy detects that the application's VM is over-provisioned for specific resources, then the proxy can request that these resources are reduced to a more suitable level. In order to fully test the improved benefits of the MCPF, real life benchmarking tests were carried out as described in the following section.

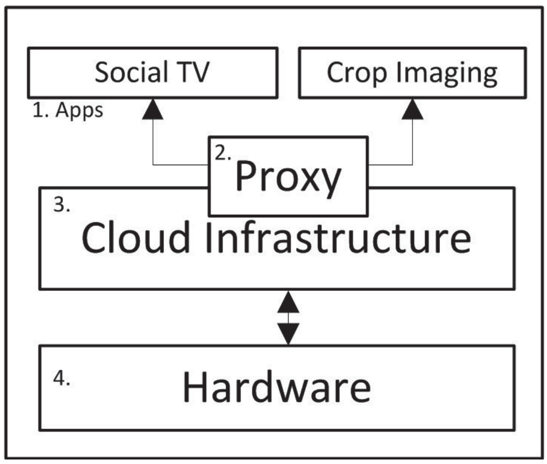

Fig. 2. High Level Design of the Mobile Cloud Proxy Function

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IV. Early Experimental Tests and Analysis

A. The IUATC UK-India Global Testbed – Phase II

As part of the India – UK Advanced Technology Centre (IU-ATC) initiatives to put in place a support infrastructure to facilitate the research and development of Next Generation Networks, Systems and Services in both countries, the UK-India EPSRC-DST project was initiated to develop a transnational testbed spanning between the UK and India. This is important to allow for early trials, adaptations and implementations of various ideas, concepts and technologies developed within the consortium and by industrial partners more widely. In the Phase II of the UK-India project, there are plans to address current research challenges in the area of Future Internet (FI) and Internet of Things (IOT) on the already developed platform from Phase I by reusing the existing technologies, equipment and services.

As shown in Fig 1., the IP core network of the global testbed spans between various universities located in UK and India. The main points-of-presence (POPs) for the UK-India global testbed in the UK are at the University of Surrey, University of Ulster and University of Lancaster. While in the India, the key POPs are located at IIT Delhi, IIT Mandi and IIT Madras with the later providing 4G LTE/LTE-A to campus mobile network.

B. Mobile Social TV Benchmarking

In order to benchmark the mobile social TV application, the UK-India global testbed was used to deploy a number of media servers and clients at key locations particularly Ulster, U.K. and Delhi, India. The benchmarking experiments were aimed to determine the baseline for the amount of resources required for application adaptation e.g., webpage caching, and resource adaptation e.g., virtual resource provision. The benchmarking results will help model the right thresholds for the MCPF.

The experiments were carried out by executing concurrent file downloads from a Wisekar server located at IITM Delhi, in order to simulate the proportional relationship between workload and propagation distance from the server. As workload volume and propagation distance from the server increase, the latency over which the transaction is involved increases as shown in Fig 2 and Fig 3. There are also, however, some anomalies associated with performance achieved,

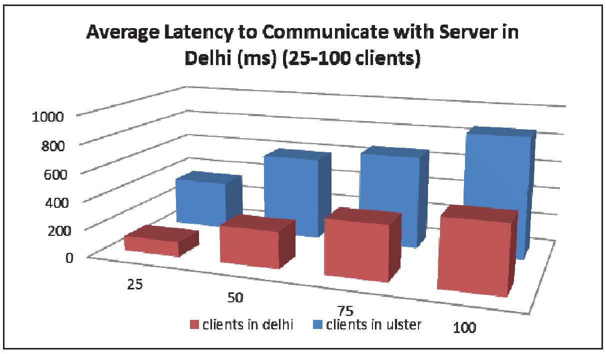

Fig. 3. Communication Latency Ulster - Delhi (12K)

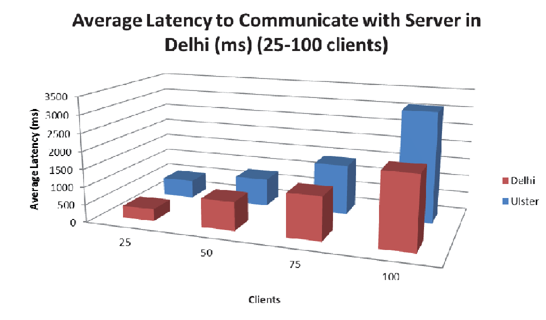

Fig. 4. Communication Latency Ulster - Delhi (55KB)

particularly during transmission of the higher volumes of traffic. When transmitting during the 55KB scenario for 50 clients, for example, there was a higher latency involved for clients residing in Delhi as opposed to those residing in Ulster (807 33 seconds in comparison to 789.32 seconds).

There was also an increase in latency, which is not proportional to the other increases in latency in the scenario involving 100 clients in Ulster (517 second for 25 clients, 789 seconds for 50 clients, 1412 seconds for 75 clients and 3098 seconds for 100 clients.). Furthermore, the network experienced inability to cope with the 55KB workload for 100 clients residing in Delhi (Figure 5); such occurrence did not occur for clients residing in Ulster (Figure 4). Further experimental work is on-going to explain these anomalies associated with performance both locally and across the long-distance path between Ulster and Delhi.

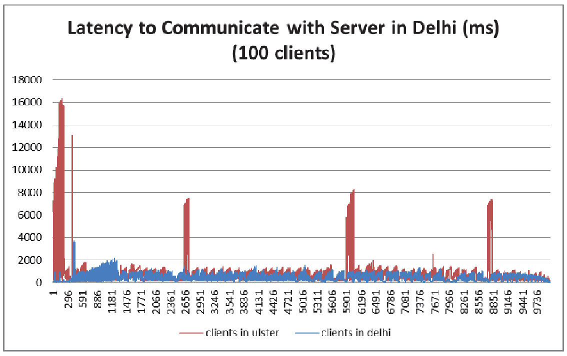

Fig. 5. Communication Latency between Ulster and Delhi (12KB, 100 clients)

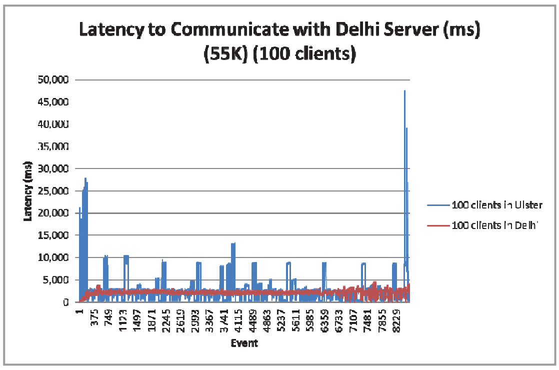

Fig. 6. Communication Latency between Ulster and Delhi (55KB, 100 clients)

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C. Mobile Crop Imaging Benchmarking

In this benchmarking scenario, a crop-imaging that allows rural farmers to capture images of (potentially) diseased crops on their mobile phones and transmit them to a cloud-based application on the public Internet. This application processes and analyses the image content, with the aim of identifying any apparent disease. Figure 6 illustrates the process involved in transmitting the image to the cloud-based application, processing the image, and returning feedback to the user.

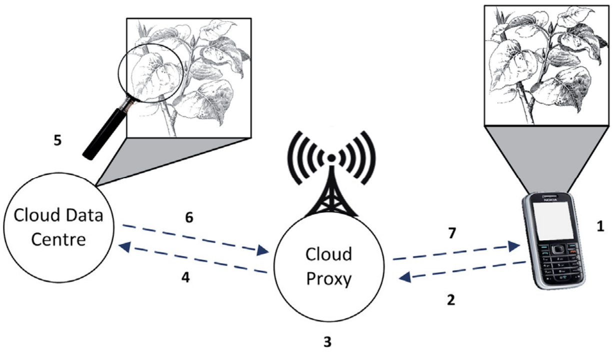

Fig. 7. Crop Image Distributed Processing

An initial prototype of the crop-imaging system was deployed on the UK-India global testbed with some nodes producing emulated user requests (i.e. transmitting mobile phone images of diseased crops), some nodes providing the functionality of the mobile cloud proxy, and a node acting as the central datacentre, from where a master copy of the application is accessible.

Each test-bed site offered a range of research functionality based on the required role assigned to the site. Mobile phone images of diseased crops are transmitted from the IITM Madras, India test-bed. These images are transmitted using a range of distributions with a simulated MCPF located at Mandi, Surrey and Lancaster sites. Image buffering, processing and analysis are carried out at each site, whenever the Madras Image Transmission Software (ITS) transmits images to the public IP at that site. The test-bed at Ulster provides the function of the central-based application. This application becomes active when "spill-over" occurs from the other proxies (i.e. their infrastructure becomes resource contended).

Although initial experimentation were carried out to assess the network links between the test-bed at Ulster and those at Surrey, Lancaster, Madras and Mandi, these experiments aim to provide baseline metrics for the physical end-to-end link between Ulster and the other sites. With this knowledge at hand, it became possible to provision distributed application flows between the remote sites and Ulster with a prior knowledge of maximum link capacity. Figure 7 shows the overall mean values for the round-trip time (RTT) of ICMP packets sent between Ulster and the respective sites, over a period of 53.5 hours. Each sample taken represented 2.7 MB of data (an example mobile phone image size). The RTT Min value represents the average RTT Min time returned for all 320 samples taken (each at a 10 minute interval). Similarly, the RTT Mean and RTT Max values show the average Mean and Max values returned, averaged across all 320 samples taken

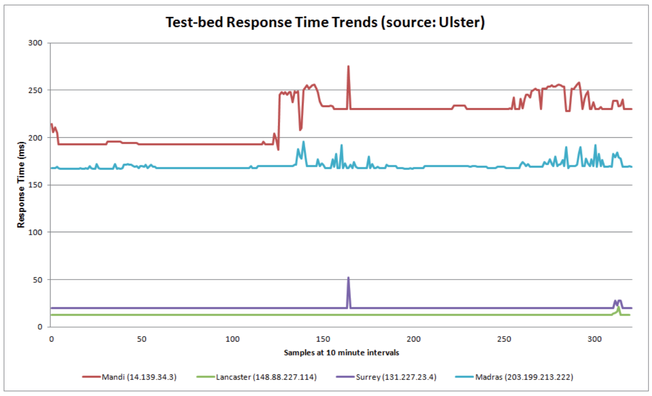

Fig. 8. Test-bed Response Times

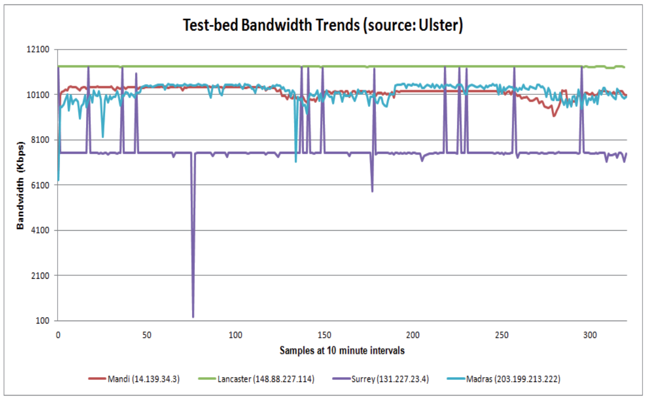

Fig. 9. Mean Test-bed Bandwidths

Figure 8 illustrates the average bandwidth values returned, over a period of 53.5 hours, for the links between the test-bed at Ulster and the test-beds at Surrey, Lancaster, Madras and Mandi.

V. CONCLUSIONS AND FUTURE WORK

The integration of mobile networks to the public Internet is still one of the key driving forces toward the evolution of the current Internet architecture. This is because it plays a key role in the "Future Internet" theme aimed at integration of our physical and digital worlds via the use of mobile sensing devices in form of mobile phones, sensors and actuators. This will in return open up new services and opportunities in the area of Internet of Things (IoT) and Machine-to-Machine (M2M) communications driving innovative visions such as smart cities, personal healthcare and e-agriculture.

In this paper we highlighted the challenges faced by accessing clouds based services in mobile environments while providing the requirements and specification for an approach to address these limitations. Based on the requirements and specifications, we then proposed an approach the will enable the seamless integration of Internet based clouds services into mobile environments while providing the building blocks for dynamic resource allocation, adaptation of transport protocols, application caching and security/resilience. Our proposed approach is based on the Mobile Cloud Proxy Function (MCPF) that exposes a dynamic and programmable interface to both cloud service providers and mobile network operators for the management of mobile resources such as spectrum and mobility management. Furthermore, we benchmarked the proposed solution using two resource intensive applications – social TV and crop imaging – while highlighting the need and importance for the mobile cloud proxy function.

Our next steps is to finalise the design of the Mobile Cloud Proxy Function while making it available to relevant standardisation bodies in are of Internet technologies and mobile telecommunications.

ACKNOWLEDGMENT

The IU-ATC (India-UK Advanced Technology Centre) of excellence in next generation networks systems and services is a virtual joint research initiative which will put in place a focused agenda to support collaborative PhD, Post Doctorate projects and joint research programs, and technology transfer between the UK and India. This UK-India consortium-based initiative has been established in direct response to a previous request from the British High Commission in India. The IU-ATC consortium has developed and matured over the years through a series of workshops supported by EPSRC and the British High Commission in India, commencing with a Technical Workshop in January/February 2006. The consortium comprises 8 research-leading universities in UK, 5 leading IITs, major industrial partners in UK and India (including companies such as BT, Toshiba, InfoSys, Wipro, Sasken, and Tejas), and a number of SMEs. The initiative establishes the first virtual India-UK Advanced Technology Centre (IU-ATC) in Next Generation Networks, Systems and Services, which will put in place the support infrastructure to facilitate, develop and enable the Digital Economy of both countries. This will be achieved through scientific investigation of the technical and functional requirements of Next Generation Networks through the promotion of industry collaboration with research-leading academic institutions and government departments.

We also acknowledge Professor Subrat Kar and Sanat Sarangi for their support in the execution of testbed profiling experiments in the Indian Institute of Technology in Delhi.

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