

# Mobile Multimedia: Reflecting on Dynamic Service Provision

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## Abstract

Delivering multimedia services to roaming subscribers raises significant challenges for content providers. There are a number of reasons for this; however, the principal difficulties arise from the inherent differences between the nature of mobile computing usage, and that of its static counterpart. The harnessing of appropriate contextual elements pertaining to a mobile subscriber at any given time offers significant opportunities for enhancing and customising service delivery. Dynamic content provision is a case in point. The versatile nature of the mobile subscriber offers opportunities for the delivery of content that is most appropriate to the subscriber's prevailing context, and hence is most likely to be welcomed. To succeed in this endeavour requires an innate understanding of the technologies, the mobile usage paradigm and the application domain in question, such that conflicting demands may be reconciled to the subscriber's benefit. In this paper, multimedia-augmented service provision for mobile subscribers is considered in light of the availability of contextual information. In particular, context-aware precaching is advocated as a means of maximising the possibilities for delivering context-aware services to mobile subscribers in scenarios of dynamic contexts.

*Keywords:* Mobile computing, Service provision, Context-aware precaching, Mobile Multimedia

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## 1. Introduction

Mobile computing has fundamentally challenged many aspects and tenets of what was perceived, and experienced, by most people in traditional computing scenarios. Though a radical paradigm shift in itself, nevertheless, it

was only over time that the nature of mobile computing began to crystallise. Indeed, it must be observed that this is an ongoing process. When the historical development of modern computing is considered, it can be seen why this is the case. If the 1960s are regarded as the beginning of the modern computing era, then conventional computing had been in existence almost 30 years before the use of computing in mobile scenarios became feasible. In this time, various techniques for engineering software solutions were developed and a consensus was growing about what constituted good practice principles. By introducing a mobile element into computing infrastructures, a further level of complexity was introduced into practically all elements of the software engineering lifecycle. In particular, data management and dissemination for mobile service delivery are interesting cases in point.

Data management for mobile users raises a number of difficulties. The ubiquitous issues of security and privacy are to the forefront of concerns for many. In particular, the issue of cache consistency, that is, ensuring that the data on the mobile device is consistent with that maintained on other devices, especially networked servers, is of particular importance. Data dissemination is dominated by the classic Push/Pull model, but its effectiveness is compromised by the inherent limitations of mobile computing. However, a more holistic view of data management and dissemination is emerging for mobile subscribers. In this view, the management and dissemination of data should be governed by prevailing contexts, particularly as these pertain to mobile subscribers.

### *1.1. Motivation*

Consumers of electronic content are a diverse group. Thus meeting their needs and expectations can provide significant challenges for content providers. A brief look at the development of the internet is illuminating. Some organisations have a significant presence on the WWW, as they view this as a significant revenue generator. One critical objective is to increase the number of visitors to their site. This is true for the major international companies as well as for individuals who may maintain a blog for their own amusement. One technique that is being increasingly adopted is that of personalisation [1]. In essence, selective attributes of WWW site visitors are captured and used to filter, customise and prioritise the content presented to the visitor. Even though the nature of mobile computing usage differs significantly from its static counterpart, this principle can also be applied to great effect with

mobile users, particularly when salient contextual elements unique to mobile subscribers are included. In addition, when mobile user behaviour is analysed, it can be seen that opportunities to deliver content pertinent to the prevailing context may arise. However, there are two key challenges that must be addressed if content providers are to take advantage of these opportunities.

1. A model of subscriber behaviour that enables correlation between their environment and their both their immediate and likely future behaviour must be constructed, such that potential contextual situations may be anticipated, and taken advantage of.
2. Content must be precached, either on the subscriber's host device or on a fixed network node such that it may be made available in that short period of time in which a select combination of contextual cues are valid.

### *1.2. Mobile Data Management*

As the mobile computing paradigm crystallized, the issue of mobile data management [2] became critically important. In particular, caching strategies in all their facets were widely investigated. A detailed description of these developments is beyond the scope of this discussion; however, the interested reader is referred to Barará [3] for a general discussion of some of the pertinent issues, and to Lee et al [4] for a discussion on semantic caching. From a historical perspective, it should be observed that much of this research took place in parallel with the WWW [5]. More recent research considers the implications for caching in peer-to-peer (P2P) scenarios [6] [7].

Elements of context have been frequently harnessed implicitly for the refinement of caching strategies. Not surprisingly, location is the predominant element [8] [9] [10]. However, a number of researchers have considered the implications of their caching and prefetching algorithms from an energy and power perspective [11] [12]. Given the limited power resources of mobile devices, and the relatively power-intensive nature of wireless transmission, effectively harnessing these elements of context can contribute to system performance and longevity.

Data dissemination models tend to coalesce around the concepts of Pull and Push [13], both in static and mobile usage scenarios. In each case, data that incorporates a dynamic component offers particular challenges [14] [15]. In addition, a range of ancillary but important issues arise. For example Lin

et al [16] consider the case for adopting intelligence in a Push model while Cheverst et al [17] reflect on usability issues in context-aware mobile systems that adopt Push/Pull models.

## 2. Context-aware Service Delivery

Given the dynamic and unpredictable nature of the average mobile subscriber's context, it can be seen that the content provider's task of preparing and delivering content such that it corresponds to the prevailing context is a complex endeavour, and one which careful planning is essential. In essence, this involves reconciling a number of conflicting objectives. Subscriber expectations must be met, the quality of their experience must be satisfactory and the service must be delivered in a timely manner. The cost must be acceptable to the subscriber while covering carrier costs and any media royalties. All of these objectives must be fulfilled within the confines of a computationally limited device, and a wireless network with low data-rates and high latency while simultaneously operating with multimedia data that is resource and bandwidth intensive.

### 2.1. *Technological Issues*

Technological issues represent a critical constraint when designing mobile multimedia services, and a detailed understanding of these limitations is crucial. As an illustration of the issues involved, three facets are now considered - the device, an archetypical context sensor and wireless communications.

#### 2.1.1. *Device*

With the exception of highly specialised niche domains, a service provider is almost invariably targeting a subpopulation that will be equipped with standard mobile phones. Such devices are characterised by limited computational resources in all their elements. This resource differential can come as a culture shock to some as subscribers who are used to operating on workstations may find the mobile experience unsatisfactory, and one in which they may need significant inducements if they are to adopt to successfully.

Working with multimedia is a computationally intensive process, and one which is compromised by the poor resources available on the mobile device. However, media capture and rendering are feasible, and for most services, these features are adequate. The small screen size is a major limitation; one quarter VGA - (320 x 240 pixels) being an upper limit and a resolution

that most high-end phones now support. For smaller resolutions, the use of visual media elements may be unsuitable. It must be observed that part of the screen is usually accounted for by a standard banner at the top and a taskbar at the bottom, thereby limiting the amount of screen estate for a third party application. In principle, the programmer has access to the entire screen; however, in doing this, the perceived Look & Feel (L&F) of the device in question may be altered. For usability reasons, it is wise to ensure that the application both appears and functions in similar manner to other applications on the device.

Finally, the interaction modality must be considered. Most devices are equipped with a 5-way navigation pad, as well as an alphanumeric keyboard that conforms to the international standard [18]. However, the use of intuitive multimodal interaction techniques such as eye-gaze, handwriting recognition and voice recognition for example, are not feasible on mobile devices, except in the simplest cases. Should it be possible to undertake the actual processing and interpretation on a fixed network node rather than on the device itself, then the options available increase; however, this is domain dependent.

### *2.1.2. Context Sensors*

Having decided to use some element of the subscriber's context, or combination of contexts, a key decision involves how the necessary context can be harvested. In some cases, it may be possible to retrieve data from some existing infrastructure - a simple example might be harvesting the prevailing weather from a nearby weather station. Assuming that quality is acceptable, and that the cost overhead is not excessive, then this is a straightforward process. A more likely scenario is that an appropriate physical sensor, for example a location-sensor or an accelerometer, must be attached or embedded in the mobile device that the subscriber already possesses. In this case, the subscriber must be motivated to acquire such a sensor, or if the business model allows it, an appropriate sensor should be provided for free. From a device perspective, there are a number of considerations that must be taken into account. Assuming the sensor is integrated into the mobile device, the continuous monitoring and interpreting of a subscriber's contextual state has implications for the power resource on the device, and as such must be quantified in some way. Secondly, the sensor must be monitored in software, and while this also has power implications, the memory consumed may have implications for service performance on the device. To clarify some of these issues, it is useful to consider one of the most useful aspects of a subscriber's

context - location.

For the most part, techniques that enable the determination of subscribers' positions can be classified as either networked-based or satellite-based. Network-based techniques [19] are inherently linked to cellular networks, and are heavily influenced by the topology of the network, which in turn is influenced by the nature of the local physical environment. The 3GPP has ratified three network-based techniques for 3G Universal Mobile Telephone Networks (UMTS) networks, and one that use satellite technologies, namely Assisted-GPS [20]. The three network-based techniques are: Cell-ID, Observed Time Difference of Arrival (OTDOA) and Uplink Time difference of Arrival (UTDOA).

A number of observations can be made about these techniques. Cell-ID gives a position which can only be accurate to within the radius of the cell. This may range from meters to kilometres. In any Public Land Mobile Network (PLMN) deployment, the cell size will not be uniform but will vary significantly between rural and urban areas. OTDOA and UTDOA are both dependent on signal measurement and, as such, need Line of Sight (LOS) conditions for an accurate reading. Crucially, they are both susceptible to fading and interference, thus the accuracy obtained may vary in a way that is difficult to quantify. Finally, all these techniques depend on the availability of network parameters, and as such, represent a service that the operator can provide but which the subscriber or service provider must pay for.

In the case of satellite technologies, the Global Positioning System (GPS) is currently the de facto standard. GPS receivers are commonly available and are increasingly being integrated with mobile devices. The accuracy of positions obtained with GPS varies but the error margin is usually of the order of 20 meters. As positions obtained with GPS are relatively accurate, and the service is free, it is an attractive solution for those service providers aspiring to deliver a services that utilises this aspect of a subscriber's context. If the application domain requires a more accurate position, the possibility of using a Satellite Based Augmentation System (SBAS) technology such as the European Ground Navigation Overlay Service (EGNOS) [21] or the Wide Area Augmentation System (WAAS) [22] may be considered. In essence, these are Differential GPS (DGPS) systems where the corrections to the GPS signal are broadcast from geostationary satellites. Most GPS receivers support this technology and position readings accurate to approximately 3 meters may be expected. A difficulty with this technology is that subscribers in urban environments and high latitudes may have difficulty accessing the signal due

to the position and the scarcity of the broadcasting satellites. Recall that the GPS constellation includes over 24 satellites while EGNOS is only being broadcast from three. A solution to this, at least in the case of EGNOS, is SISNet [23], an initiative from the European Space Agency (ESA) and involves the transmission of the EGNOS signal (that is, DGPS corrections) over the internet. For mobile subscribers, there is a computational and cost overhead in using this service.

It is important to note that all the techniques described, with the exception of Cell-ID, work best outdoors and that their potential in indoors scenarios is limited. Indoor solutions require another suite of technologies, and at this time at least, there is no standardized solution for indoors. A number of techniques have been described in the literature [24], but of all these, the UBIsense system [25] is one that is receiving most attention.

From a deployment perspective, an increasing number of devices are being manufactured with GPS chips, and this trend will continue. Currently, the easiest way to integrate a GPS device is to acquire a Bluetooth enabled unit, as a significant number of mobile devices come with Bluetooth. The subscriber can host the device on their person such that the antenna is visible. As Bluetooth usually emulates a standard serial port, communicating with the device is not difficult. However, the device must be continuously monitored if the subscriber is to be tracked accurately. A dedicated thread is most intuitive way of managing the device. There is a memory overhead, possibly of the order of 512 bytes. This in itself is manageable but if the application itself is heavily multithreaded, for manipulating with other contextual elements for example, there may be performance issues.

GPS data conforms to the NMEA specifications [26], and broadcasts from the GPS device are in the form of textual sentences, each labelled with a particular tag that distinguishes it and facilitates its parsing and subsequent interpretation. There are three tags of particular interest:

1. \$GPGSA - This indicates the operating modes, the satellites used in the position calculation and various Dilution Of Precision (DOP) values. By examining the "fix" (2D or 3D navigation), and the DOP values, the position calculation can be quantified.
2. \$GPGGA - This returns a latitude and longitude position as well as a position quality indicator, which can indicate whether this is a standard or differential GPS solution.
3. \$GPRMA - This indicates both position and bearing, thus giving a

Table 1: Cost of monitoring a subscriber over 1,2,4 and 8 hour intervals @ 1 cent per KB.

		1 Hour		2 Hour		4 Hour		8 Hour	
<i>NMEA Tag</i>	<i>Size (bytes)</i>	<i>Size (bytes)</i>	<i>Cost (cent)</i>	<i>Size (bytes)</i>	<i>Cost (cent)</i>	<i>Size (bytes)</i>	<i>Cost (cent)</i>	<i>Size (bytes)</i>	<i>Cost (cent)</i>
\$GPGSA	49	8820	86	176400	172	452800	345	705600	689
\$GPGGA	64	115200	113	230400	225	460800	450	921600	900
\$GPRMC	68	122400	120	244800	239	489600	478	979200	956
Total	181	325800	318	651600	636	1303200	1273	2606400	2545

more complete state of the subscriber’s spatial context.

In Table 1, an example of each type is presented, their size in bytes, and a cost indicator. While cost is not excessive, at least at first sight, it can be seen that data and cost overheads should be factored into the design. However, if the position can be calculated on the device, then it is only necessary to transmit the position (a tuple of longitude, latitude and bearing) at appropriate intervals, thus reducing the amount of data traffic and making a significant cost saving. On average, a standard position would require 16 bytes (including a DOP parameter) while it would require 181 bytes to consume the equivalent three NMEA sentences.

### 2.1.3. Wireless Networking

Service providers and subscribers are dependent on the network operator for transport of data, and as such are constricted by the characteristics of their networks. Usually, there are a number of network operators all vying for custom, and depending on the nature of the proposed service, one may offer a suitable package. However, it must be understood that network operators are innately conservative, and their first priority is to ensure that their networks are operational at all times. Thus, operators will not entertain extraordinary demands by service providers.

High latency and poor data rates have traditionally compromised the effectiveness of wireless data networks. In recent years, the situation has improved, and this trend will continue. However, depending on the geographic area where the service will be deployed, it is possible that the networks of a number of different operators may need to be availed of. This is not a problem in itself, but these networks may vary and it is important their characteristics be understood, as it is necessary to ensure that the service

will operate satisfactorily under variable networking conditions. As an example of this, 3G networks were deployed in an incremental basis - initially in urban areas and the selective rural areas, for example beside motorways. However, should the 3G base station be obscured, then the subscriber's phone would automatically connect to an older GPRS base station. For standard voice traffic, this is not a problem. For data traffic, such a change would have serious implications. In practice, a service provider must factor in the heterogeneous landscape that characterises wireless telecommunications.

In general a network operator will not guarantee wireless data rates. It depends on the number of subscribers using the network at any given instant. Not only that, but operators will not commit to a minimum data rate, thus worst case scenarios cannot be constructed. This is a potentially serious problem for service providers, as they cannot design a service with guaranteed Quality of Service (QoS) parameters. Indeed, this has led some researchers to question the validity of the QoS concept, at least from a subscriber perspective. A Quality of Experience (QoE) metric [27] has been suggested as a more effective alternative. Ultimately, it is envisaged that the incorporation of IP Multimedia Subsystem (IMS) [28] technologies will address the critical issue of QoS in broadband wireless networks.

## *2.2. Design*

A mature understanding of the technical possibilities and limitations is an essential prerequisite for service design. Three essential models must be constructed - a context model, a media model and a delivery model.

### *2.2.1. Context Model*

Acquiring elements of a subscriber's context introduces additional complexity into the design and delivery process. It beholds the service provider to ensure that the cost of this endeavour is fully understood and justified, and in this case, cost is not just limited to the financial realm. It must be ascertained that the selective contextual cues can be obtained easily and transparently, and with minimum disruption to the subscriber. In addition, it must be further ascertained that the contextual situation can be interpreted within the appropriate time constraints.

Consider the case of spatial context or location. To acquire this aspect of their context, the subscriber must be equipped with either a GPS sensor or the network operator must have a capability to determine it to a sufficient accuracy. To interpret spatial context in practice, it is essential that a model

of the physical environment be obtained. A number of agencies, both governmental and commercial, can supply such models, usually in the form of Geographic Information System (GIS) data. Depending on the application, additional overlays can be obtained, for example a vector street map. A more likely scenario is that an application specific overlay must be developed. To determine the distance between the subscriber and some object of interest, a number of formulae can be adopted. The standard Euclidean distance can be calculated in the usual way. In practice, this assumes a straight path between the subscriber and the object in question. This may not be the case, and if a more accurate measurement is needed, it may be necessary to consider another technique, possibly Manhattan distance, if the geographic area in question is in a city.

Finally, it can be useful to classify context elements according to their dynamicity. Some context may be almost semi-static in nature, for example, personal profile data. Such data may be stored on the network, rather than on the mobile device. Context that is sufficiently dynamic must be captured in situ; but its processing and interpretation may need to take place elsewhere. This process must be quantified.

### *2.2.2. Media Model*

In a wireless multimedia service, individual media components will constitute a significant portion of any service payload. Given the poor data-rates that characterise wireless communications, it is essential that the trade-off between subscriber expectations and requirements, and selected media elements or formats be understood and justified. In some cases, high quality media will be required; in other cases, excessive quality will not increase subscriber satisfaction, and may have a detrimental effect on device performance.

A potential complication occurs when the respective abilities of mobile devices to render different media are considered. This capability differs between devices, and even between similar devices from the same manufacturers. In all cases, manufacturers will indicate which media formats their device supports. However, some caution must be exercised here. Frequently, a device will support a dedicated player for some media element. Such a player is usually optimised for the device in question, and constructed as a stand-alone application. However, third party service providers may not be able to access such applications, customise them or integrate them into their services. Rather, the application runtime environment supported by the device will

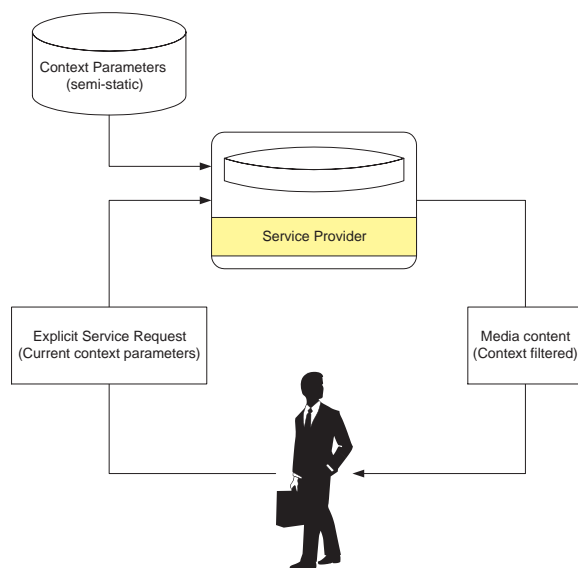


Figure 1: A context-aware pull approach.

usually support a suite of generic media players and codecs. It is beholden on service providers to identify those formats that are most appropriate for the domain in question, and which will perform on the widest variety of devices. One standard approach is to maintain a multimedia database that contains media elements stored in very high resolution formats. These are then converted on-the-fly as needed.

### 2.2.3. Delivery Model

In essence, there are two classic models of data dissemination - Pull and Push. Both of these can be augmented by salient aspects of the subscriber's context, as per application domain requirements. There is a third model of particular relevance when considering dynamic data - Context-aware pre-caching. This could be implemented under the guise of a push or pull approach. For the purposes of this discussion, it will be considered separately as it is an apt solution in dynamic contextual scenarios.

In the case of Context-aware Pull (Figure 1), the service provider takes a relatively passive role, almost restricting them to the role of a content repository. Should the subscriber provide some contextual cues, or if the service provider has acquired some semi-static context elements, then there may be scope for adaptation and personalisation. Implementing a Pull approach

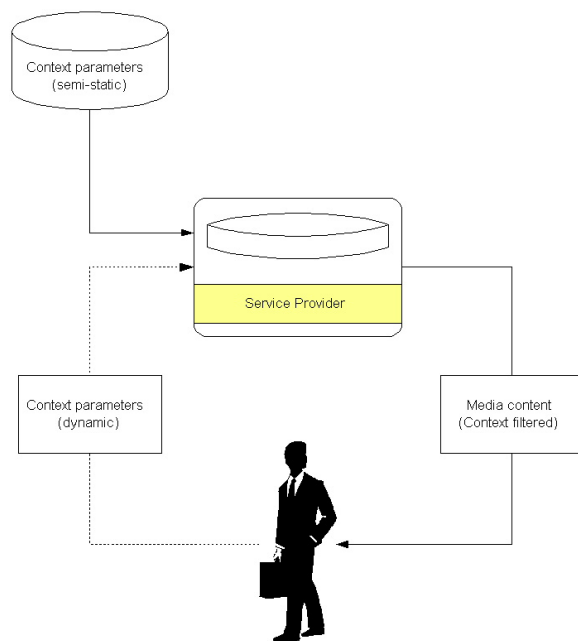


Figure 2: A context-aware push approach.

is relatively straightforward and the onus is on the subscriber to initiate sessions. This limits the potential for the service provider to act in an opportunistic and proactive fashion in response to emerging context scenarios.

In a Context-aware Push scenario (Figure 2), the service provider is responsible for delivering the data on to the subscriber's device. Hence, every effort must be made to ensure that the data is relevant and timely. Contextual cues offer a means of achieving this, and their effective utilisation minimises the amount of redundant data and increases user satisfaction. In the former case, there is a cost saving; in the later case, there is the possibility of additional revenue.

Finally, a context-aware precache approach (Figure 3) may be considered. In this scenario, a certain contextual state may be envisaged as being likely to arise in the near future. When this state arises, a window of opportunity exists to provide a service to the subscriber. This window may be quite short in duration; hence every effort must be made to avail of it. Consider the mobile commerce domain. A mobile subscriber may be passing a shop, and only in this short time span while they are in the vicinity of the shop does an opportunity exist to deliver an advertisement to their mobile device,

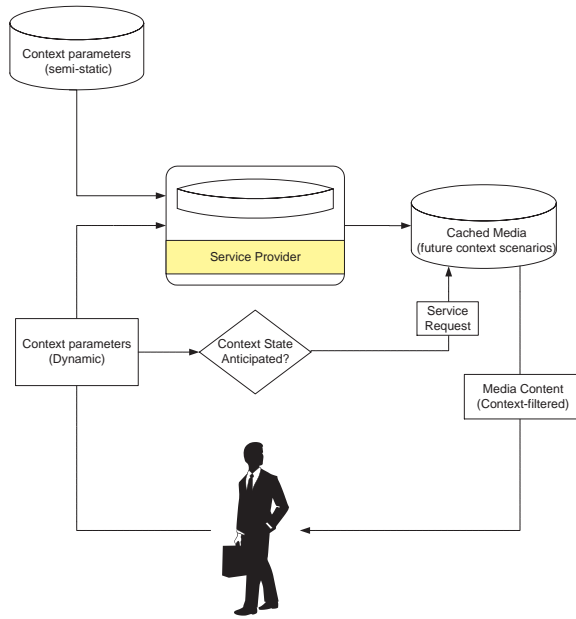


Figure 3: A context-aware precache approach.

and hopefully motivate them to actually enter the shop. The delivery cycle can be shortened if this situation has been anticipated, and the advertisement prepared in advance. If there is a multimedia processing component, there may be a considerable time saving. Though not quantifying this time saving, it may mean the difference between gaining a customer and failing to do so. The greater the multimedia component, the greater the need for acting in a proactive and anticipatory fashion. Precaching can occur either on the service provider's fixed networked node or on the subscriber's mobile device. In both cases, the service can still be modelled in either a push or pull fashion. By hosting the precached data on the local device, the effects of issues like network latency are reduced though there may be a cost penalty. However, by making the precache available locally, the service can be delivered instantly once the appropriate contextual state has been realised. In this way, the service can be delivered even in those situations where the duration of the appropriate contextual state is quite short. A practical illustration of these issues will now be presented in Section 3.

### 3. Context sensitive content delivery in the tourist domain

As a practical illustration of the issues discussed in the previous section, a brief description of an etourism application is now presented from a context and mobile multimedia perspective. The application in question - Gulliver's Genie [29] [30] has been an ongoing project for a number of years. It is extensively described in the literature and it has been the subject of user evaluations [31]. The overall objective of the Genie is to deliver multimedia presentations to tourists on those attractions that they encounter while roaming.

In brief: the Genie is modelled and implemented using the intelligent agent paradigm. As the tourist roams, their prevailing spatial context is captured and interpreted on their device. Aspects of this are regularly passed to agents on a network node, who proceeds to identify and construct multimedia presentations, in anticipation of the tourist encountering an attraction while roaming. Given the likelihood of a context state arising, the presentation is actually downloaded and precached on the device. Should the appropriate contextual state be triggered, this presentation will be rendered for the tourist immediately. More recently, the possibility of using the Synchronized Multimedia Integration Language (SMIL) [32] was validated.

#### 3.1. Context and the Genie

Spatial context, personal profile and cultural interest profile are the three key elements of context harvested by the Genie.

Spatial context incorporates the tourist's geographical position and bearing. This is harvested from a normal GPS sensor attached to the device. Periodically, this is dispatched from the mobile device to a fixed network node. In this way, an approximate model of tourist behaviour can be maintained on the network node, and a more detailed model maintained on the device. Fundamental to the construction of this model is the availability of a georeferenced model of the area. Using this as a basis, a model of the key tourist attractions can be constructed quite easily.

Personal profile includes those attributes of the tourist that are unique to their person. Age, nationality and spoken languages are three examples. These attributes change slowly over time, can be stored on a fixed networked node and enable the personalisation of the delivered service and constituent content.

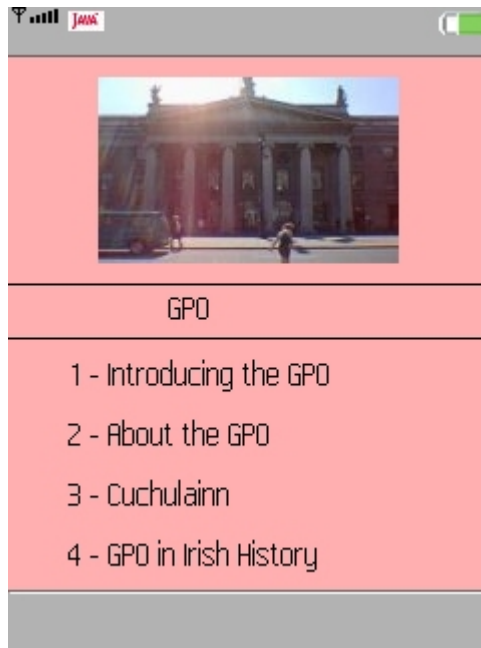


Figure 4: A presentation on the GPO in Dublin.

Cultural interest profiles include a list of cultural interests particular to the tourist in question. This profile is overtly dynamic but not extremely so. Overtime, a preference for certain cultural interests will emerge. This will enable filtering and ranking of content. However, this does oblige the Genie to observe and interpret tourist interactions. Initially, the tourist fills in a questionnaire, which is used to seed their profiles. The personal profile remains relatively static; however, the interest profile can only be refined by explicitly observing tourist interaction. What is explicitly selected, and implicitly ignored, is observed by the Genie, and used to update the cultural interest model. There is a communications overhead here, but it is insignificant.

### *3.2. Media and the Genie*

A Genie presentation consists of a number of Links which in turn are composed of individual media elements. Link, short for the term hyperlink, is a legacy term from when the Genie was modelled as a mobile WWW browsing application. This is no longer the case but the term endures. Each Link comprises a combination of either images and sounds, or a video sequence.

Table 2: Structure and media composition of a Genie presentation concerning one of Dublin’s most important tourist attractions - The General Post Office (GPO).

<i>Link</i>	<i>Type</i>	<i>Title</i>	<i>Image</i>	<i>Audio</i>	<i>Video</i>
1	Anchor	Introducing the GPO	✓	✓	X
2	Required	About the GPO	X	✓	X
3	Model - Folklore	Cuchulainn	✓	✓	X
4	Model - History	GPO in Irish History	X	✓	X



**You are now approaching the  
General Post Office, or GPO,  
one the most famous  
landmarks in Dublin.**

Figure 5: The Anchor Link is mandatory and introduces the attraction in question. The text beside the image is a transcript of what the tourist actually hears.

Though rendering a video on a mobile device is indeed feasible, the option is not availed of in practice as their download time is excessive from a cost perspective. More importantly, it is questionable at least at this particular time juncture if the use of video would augment the subscriber experiences such that the cost/benefit ratio would be satisfactory.

A template of a simple Genie presentation may be seen in Table 2, and what the subscriber experiences may be seen in Figure 4. This presentation is for one of the most important buildings in Dublin - the General Post Office (GPO). The presentation is structured as follows:

The first Link, or Anchor Link, introduces the tourist to the tourist attraction (Figure 5). Its purpose is simply to allow the tourist orientate themselves and confirm that they are at the correct location. If interested, they can then select one of the other Links for further information.

The second Link is a required Link; hence, it is included in every presentation, regardless of context and personal profile (with the exception of language). Information contained in this presentation would be aimed at the broadest possible audience and, as such, would be general in nature. In this case, a brief overview of the attraction is presented (Figure 6).



**The GPO is one of the world's oldest postal headquarters. The original foundation stone was laid in 1814, and the building was completed 4 years later in 1818. The total cost was £50,000. As can be seen, the building is modelled on the Greek style, and is fronted by 6 ionic pillars. It is built of Wicklow granite, and Portland stone is used for the portico. Three statues can be seen on top of the building. These are Hibernia in the centre with Fidelity to her left and Mercury to her right.**

Figure 6: A required link is mandatory. In this case, it presents a brief overview of the GPO.



**Within the GPO is a sculpture of the legendary Irish warrior - Cuchulainn. This is dedicated to those who died in the Easter rising. The text of the Proclamation of independence, and the names of the signatories, are inscribed on the base.**

Figure 7: A presentation for those with an interest in folklore, in this case prompted by the proximity of a sculpture of Cuchulainn.

The third Link is related to the tourist's Interest Model. In this case, the cultural interest is in the folklore domain. Hence, a presentation about the mythical Irish warrior Cuchulainn (translated - hound of Culainn) is presented as there is a famous sculpture of Cuchulainn in front of the GPO. In this case, a new image is depicted to bring the tourist's attention to the sculpture (Figure 7)

Likewise, the fourth Link is associated with a cultural interest - History. In this case, a brief history of the GPO is provided to tourists who have expressed an interest in this topic. (Figure 8).

### *3.2.1. Prioritizing and Filtering Multimedia Content*

Once all the media content associated with a tourist attraction has been identified, the next stage is to filter that content according to the tourist's profiles. Recall that the only metadata or semantic tags associated with individual multimedia components is that of language; it is the Link itself that is semantically tagged from a profile perspective. Examples of Link



**The GPO is inextricably linked with the foundation of the Irish State. It was the headquarters of the Easter Rising which took place on Easter Monday 1916 which ultimately led to the formation of the independent Irish Republic. This garrison maintained a presence in the GPO for over a week before surrendering. However, only a shell of the original building remained standing. It would be another 13 years before the GPO reopened for business.**

Figure 8: The GPO has witnessed some of the most pivotal moments in Irish History, thus a presentation available for those with an expressed cultural interest in Irish history.

Attribute	Value
Tourist Attraction	General Post Office   National Museum   Dublin Castle   .....
Media elements	Image & Audio   Video
Link Type	Anchor   Required   Model
Link Category	Parent   Child
Language	Irish   English   Italian   French   German   .....
Ethnicity	Irish   Japanese   Canadian   American   African   .....
Age Group	Child   Teenager   Adult   .....
Occupation	Artist   Architect   Engineer   .....
Cultural Interest	Art   Architecture   Folklore   History   Literature   Religion   ...

Figure 9: Semantic tagging of enabling personalization and content filtering.

attributes, and the values that they can adopt are illustrated in Figure 9. Various profile attributes can be catered for. For example, a very detailed link could be defined for Japanese adults who work in engineering with an interest in folklore. To digress slightly, it can be seen that the initial content aggregation and tagging stage is key, and that it is precisely at this stage that

### Sample Commitment Rules for Content Identification

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//On identifying the nearest attraction, the presentation agent must be dynamically assembled
BELIEF(nearestExhibit(?tourist, ?attraction)) =>
COMMIT(Self,Now,BELIEF(true),request(agentID(PresentationAgent,?address),BuildPresentation
(?tourist, ?attraction)));

//Before a presentation can be assembled, the tourist's profile must be retrieved
BELIEF(profileRequired(?tourist)) =>
COMMIT(Self,Now,BELIEF(true),request(agentID(ProfileAgent,?address),returnProfile (?tourist,
?attraction)));
//For each characteristic of the tourist's profile, corresponding content (links) must be identified, if
available.
BELIEF(profileAttribute(?tourist, ?attribute)) => COMMIT(Self,Now,BELIEF(true),
extractContent(?attribute));
//Once all the profile related content has been identified, it must be ranked.
BELIEF(presentationAvailable(?tourist)) => COMMIT(Self,Now,BELIEF(true), rankContent(?tourist,
?history));
```

Figure 10: Sample commitment rules utilised by the agents for presentation assembly.

the service's unique and differentiating characteristics can be realized. The person or people who undertake the initial tagging process must be extremely knowledgeable about the subject matter, and be capable of relating this to their audience. No technology can be expected to counteract the cumulative effect of poor media selection and inappropriate use of semantic tags.

Finally, it is necessary to prioritize the content. Only Links associated with a particular cultural interest are ranked in the order of the importance the tourist has attached to a particular cultural interest. This ranking is based on the tourist's interaction history. At this stage, a complete presentation is available for rendering. However, it may be necessary to refine it further in light of cost, for example. Some strategies for this will be outlined in Section 4.2.

As the Genie is modelled and implemented using the intelligent agent paradigm, one agent is assigned the task of presentation preparation. This agent uses various commitment rules to fulfil its task. An illustration of these kinds of rules may be seen in Figure 10. However, it should be noted that the agent may be regarded as a wrapper for the technique employed. Thus an agent could be developed that incorporates other advanced techniques such as machine learning, Case Based Reasoning (CBR) and so on. Such an agent could be seamlessly slotted in to the existing architecture, provided it conformed to the appropriate agent profile or template, and complies with the current ontology.

Table 3: Implications of chosen image format on download times.

<i>Link</i>	<i>PNG</i> (KB)	<i>GIF</i> (KB)	<i>JPEG</i> (KB)	<i>DELTA</i> (KB)	<i>GPRS</i> (sec)	<i>3G</i> (sec)
1	34	19	6	28	5.7	1.5
2	-	-	-	-	-	-
3	38	19	17	21	4.3	1.1
4	-	-	-	-	-	-
<b>Total</b>	72	38	23	49	10	2.6

### 3.2.2. Implications of Media Selection

As an illustration of the importance of media format selection, the effects of media selection are now explored.

For the sample Genie presentation just discussed, there are two image components. The image associated with the first presentation element is the default image for the second and fourth presentation elements. The third element has a distinct image due to the nature of the material being presented. The sizes of PNG, GIF and JPG formats for each image can be seen in Table 3. PNG produces the largest files while JPG produces the smallest. To put this difference into perspective, an additional 49KB would be transmitted if the PNG format had been selected. The implications of this are that under a basic GPRS connection, it would take 8 seconds longer to download the presentation. In the case of a 3G connection operating at 300 kbs, it would add just over 1 second to the download time.

In the case of audio, the effect is more pronounced as the files are invariably larger. The WAV format consumes the most KB while the most efficient is the AMR format. As can be seen from Table 4, the net difference is 540 KB for the entire presentation. This would mean an additional 88 seconds to the download time in the case of a GPRS connection or 15 seconds in the case of a 3G connection. Thus prudent selection of media formats can have a dramatic effect both on the cost and the timely delivery of data.

In terms of timeliness of the delivery of the multimedia presentation, it is instructive to reflect on the average walking speed of a normal person. Clearly, this will vary according to the nature of the terrain and the physical well-being of the tourist. However, if we assume a normal pedestrian walking

Table 4: Implications of chosen audio format on download times.

<i>Link</i>	<i>Wav</i> (KB)	<i>MP3</i> (KB)	<i>AMR</i> (KB)	<i>DELTA</i> (KB)	<i>GPRS</i> (sec)	<i>3G</i> (sec)
1	58	30	12	46	9.4	2.5
2	171	170	55	216	44.2	11.8
3	127	64	26	101	20.6	5.5
4	222	112	45	177	36.2	.6.6
<b>Total</b>	678	376	138	540	110	29

speed of 1.25 m/s [33], it can be seen that the tourist would have moved an additional 21 meters in the time it would have taken to just download the presentation if the wav format had been chosen. In the case of large tourist attractions that have a significant geographical footprint, this is not such a problem. However, that is frequently not the case, and it can be easily envisage that small specialised attractions such as sculptures could get overlooked. And it is in precisely bringing the tourist’s attention to such attractions that offers such potential for improving their experience. In the next section, how this is achieved is considered.

#### 4. Context-aware Precaching in Practice

In light of the previous discussion, there are two key elements that need to be reflected on when considering context-aware precaching. The first concerns the anticipation of, and the subsequent identification of, the subscriber’s contextual state. The second concerns the generation of content, and its dissemination to the subscriber, in light of dynamic contextual states.

##### 4.1. Anticipation of the Contextual State

To anticipate a contextual state arising, the necessary element(s) of context must be continuously observed, and some cues must be available to suggest a possible future contextual state. In the case of position, it is the availability of a physical environmental model that enables this. A position sensor allows position and direction be monitored. It is only in correlating this with an environmental model (a map being the simplest implementa-

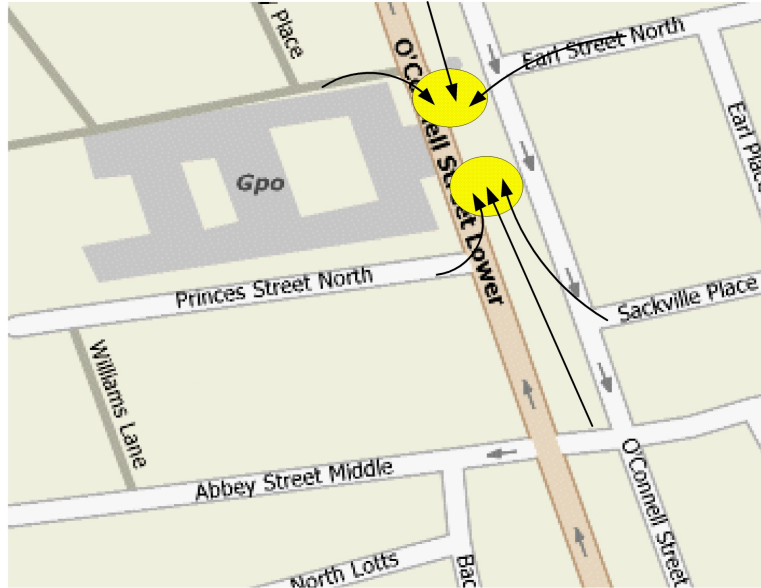


Figure 11: Specifying the trigger points is critical to ensuring the tourist receives the presentation when the most suitable context prevails.

tion of this model), that meaningful contextual states can be identified, and possible future states envisaged.

Consider the case of a tourist approaching a historical building. They may approach it from different avenues; and even though they are obviously converging on the building, there is a risk that their trajectory may change. This risk is omnipresent and must be acknowledged, but the nearer the tourist is to the building, the less chance of it occurring. To maximise context identification, the building must be modelled. In certain cases, a single geographic position denoting the centre, and an approximate radius is sufficient. In complex cases, spatial objects may be utilised. One effective but simple approach is to model the building in terms of key points in which it can be approached from. Using the GPO as an example, it can be seen from Figure 11 that there are two such points. These points are trigger points and represent the optimum positions from which a presentation on the GPO should be initiated; or in other words, they represent those points at which it is envisaged that the prevailing contextual situation will be most suitable for information presentation. At this point, the presentation must be available irrespective of delivery model engaged. It can be precached on the server for

access by Pull, or a Push mechanism can be commenced if a streaming technology is used. But for precaching the content on the device, the outstanding challenge is how to identify when the process must commence such that the content is completely precached when the tourist reaches the trigger point.

Four elements - data rates, content payload, walking speed and distance from trigger point are fundamental to identifying that moment for beginning the precaching process. Using walking speed and distance, an approximate time can be calculated. The inherent error in GPS is a source of uncertainty in the calculation, but can be averaged. Though the walking speed is also an average, this may be regarded as a conservative value as in practice as there will almost invariably be delays due to window shopping, waiting at pedestrian lights and so on. How the content payload may be adjusted is discussed in the next section; however, the payload can be constructed on the fly, in response to the contextual situation at hand, or a number of potential candidate payloads be constructed, precached on the networked node and the most suitable one dispatched to the device. Data rates represent the key problem as the number of users on a network determines the effective data rate. In principle, there should be a lower boundary, but it is the authors' experience that network operators will not commit to this. Thus, an average may be identified based on observation. The appropriate content payload is then dispatched for precaching on the device in anticipation that it will be available for access in a timely manner.

Final responsibility for identifying the appropriate contextual state for rendering the content will usually reside on the remote device, as will responsibility for bringing the content to the subscriber's attention. In practice, there will be time interval over which the contextual state will remain valid. Due to the position error, this has to be assumed. A useful heuristic concerns the subscriber's behaviour in the vicinity of the trigger point. They will converge on this and then diverge (Figure 12). Hence, a distance can be specified that defines a zone of activation in which the contextual state (at least from a position perspective!) remains valid.

#### *4.2. Content Refinement*

In light of the previous discussion, the challenge is to reduce the amount of content transmitted such that it is guaranteed to reach the subscriber prior to the envisaged contextual situation arising, yet is adequate for a satisfactory experience. A solution to this lies in prioritization of the constituent elements

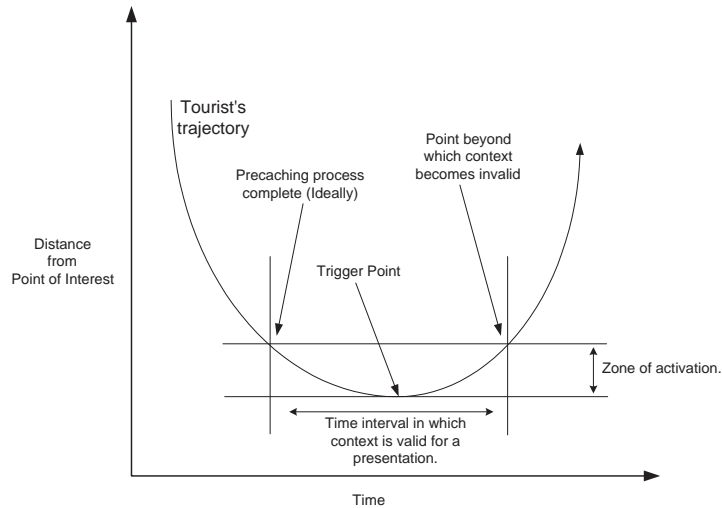


Figure 12: Once the tourist diverges from the trigger point, the presentation will commence provided that they are still with the predefined distance of the Point of Interest.

in the content, and through the use of policies specified by the subscriber or service provider.

Recall from Section 3.2 that the menu structure described was one-dimensional, and that the content was prioritised within this according to mandatory items and the cultural interests. A nested menu hierarchy is also supported. The purpose behind this is to enable subscribers, should their interest be aroused, to request further information. As an illustration, consider the hierarchy illustrated in Figure 13. In this case, the item “About the GPO” has been augmented with addition material which is accessed by a separate menu structure. By selecting any of the items, further information is given. Though useful, this information is not a priority; thus, it is not urgent that it be precached. On selecting one of these items, the necessary multimedia files can be *Pulled* down immediately. There will be a time delay, but because the subscriber is motivated, this will be perceived as tolerable, provided it is not excessive. In summary: an appropriate menu hierarchy can be harnessed to structure and prioritise the content, realizing a partial precaching solution, which may be viewed as a hybrid Push-Pull model.

Specifying policies are a simple but effective method for limiting the content being distributed. A content provider may negotiate a deal with a network operator that restricts the amount of content they can push at certain

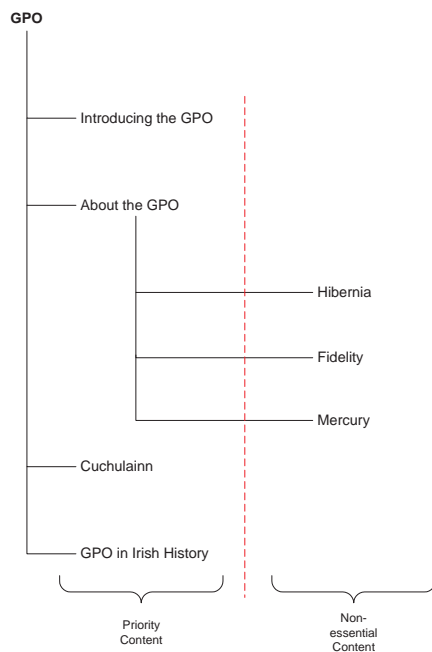


Figure 13: Precaching selective hierarchies in a menu structure offer a useful method of prioritising content.

times, or may charge a premium rate for transmitting content at other times, for example. Thus the policies that they adopt must reflect their agreement with the operators.

Similarly, a subscriber may define certain policies when subscribing to the service, after negotiating with the service provider. For example, they may request that content be precached in 512KB chunks, and that they will explicitly request any further content that they require.

In essence, parameters resulting from policy specification are effectively further elements of context that must be considered in the delivery of the service.

## 5. Conclusion

Delivering multimedia-enriched services in situations of fluctuating context raises particular difficulties for service providers. In the case of mobile subscribers, the situation is exacerbated due to the limited computational and communication capacity of the average mobile device. Augmenting the

traditional Pull/Push dissemination approaches with appropriate context parameters offers great potential for customising and personalising services. In cases of highly dynamic contextual situations, a context-aware precaching approach is advocated. Such an approach offers an effective strategy for minimising the inherent limitations of mobile computing technologies while enhancing the capability of content providers to take advantage of prevailing contextual conditions, even in cases of highly dynamic circumstances.

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