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BRILLIANCE OF SERVICE IN MOBILE COMPUTING ENVIRONMENTS - A SURVEY

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Abstract:-
The specification and management of Brilliance of Service (BoS) is important in networks and distributed computing systems, particularly to support multimedia applications. The advent of portable lap-top computers, palmtops and Personal Digital Assistants with integrated communication capabilities facilitates mobile computing. This paper is a survey of BoS concepts and techniques for mobile distributed computing environments. The requirements of current and future mobile computing are examined and the services required to support mobility are discussed Generic concepts of BoS specification and management are overviewed followed by an analysis of the BoS work specific to mobile computing environments.

Keywords: Mobile systems, nomadic systems, portable computers, Brilliance of service, multimedia, context aware computing.

1. Introduction

The availability of light-weight, portable computers and wireless communications has made mobile computing applications practical. An ever more mobile workforce, home working, and the computerization of inherently mobile activities are driving a need for powerful and complex mobile computer systems and applications integrated with fixed systems. Mobile cellular telephony is widely available and computers are being integrated with these telephones to form mobile computing devices. Many businesses are dependent on distributed, networked computing systems and are beginning to rely on high-speed communications for multimedia interactions and Web-based services. Users are now requiring access to these services while travelling. In addition new multimedia applications are emerging for Web-enabled telephones and mobile computers with integrated communications.

Multimedia applications require more sophisticated management of those system components, which affect the Brilliance of Service (BoS) delivered to the user, than for simpler voice or data-only systems. The underlying concepts of bandwidth, throughput, timeliness (including jitter), reliability, perceived Brilliance and cost are the foundations of what is known as Brilliance of Service. However, portable computers introduce particular problems of highly variable communication Brilliance; management of data location for efficient access; restrictions of battery life and screen size; and cost of connection, which all impact the ability to manage and deliver the required BoS in a mobile environment.

The assumption that BoS will be provided and maintained, without some guarantee or notification of inability to deliver, is seriously flawed from a business and technological perspective. In many applications late information has ceased to have any value, and in “hard” real-time applications may be dangerous, or have financial repercussions. Many are prepared to tolerate slow computer interactions, or try to overcome problems

By installing more processing power, or communication capacity. In many cases, over-dimensioning of the system is not economic and mission-critical real-time applications cannot simply trust this uncertain approach.

Much progress has been made on providing the ability to manage BoS. Formal notations, standards, and practical implementations, particularly in the field of networks, but also more recently in systems software now exist for this. While the underlying technologies of BoS and mobile systems are well understood, the combination of the two problems has only recently started to be addressed [1], [2]. This paper surveys the literature on BoS for mobile computing systems, rather than for wireless telecommunications.

2. Overview of Brilliance of Service

Management of BoS includes various aspects, relating to the nature of perceived Brilliance. This section provides an overview of BoS concepts and both static and dynamic techniques for managing BoS. A more comprehensive overview of architectures supporting BoS is given in [16].

2.1 Definitions and Categories of BoS

This overview of what is BoS and how to specify it is based on [2] whose treatment is primarily concerned with multimedia.

2.1.1 BoS Characteristics

BoS defines non-functional characteristics of a system, affecting the perceived Brilliance of the results. In multimedia this might include picture Brilliance, or speed of response, as opposed to the fact that a picture was produced or a response to stimuli occurred. Table 1 shows the main technology-based BoS parameters.

Table 2 summarizes the main user-based parameters. User level BoS requirements are described as perceived Brilliance and then mapped to lower level BoS characteristics and describes a selection of Brilliance characterizations in terms of BoS parameters and value ranges, for various data types.

Table 1 Technology-Based BoS Characteristics

Category	Parameter	Description / Example
Timeliness	Delay	Time taken for a message to be transmitted
	Response time	Round trip time from request transmission to reply receipt
	Jitter	Variation in delay or response time
Bandwidth	System level data rate	Bandwidth required or available, in bits or bytes per second.
	Application level data rate	Bandwidth required or available, in application specific units per second, e.g. video frame rate
	Transaction rate	Number of operations requested or processed per second
Reliability	Mean Time To Failure (MTTF)	Normal operation time between failures.
	Mean Time To Repair (MTTR)	Down time from failure to restarting normal operation
	Mean Time Between Failures (MTBF)	MTBF = MTTF + MTTR
	Percentage of time available	MTTF / MTTF + MTTR
	Loss or corruption rate	Proportion of total data which does not arrive as sent, e.g. network error rate

Table 2 User-Based BoS Characteristics

Category	**Parameter**	**Description / Example**
Criticality	Importance rating (priority)	Arbitrary scale of importance, may be applied to users, different flows in a multimedia stream, etc.
Perceived BoS	Picture detail	Pixel resolution
	Picture colour accuracy	Maps to colour information per pixel
	Video rate	Maps to frame rate
	Video smoothness	Maps to frame rate jitter
	Audio Brilliance	Audio sampling rate and number of bits
	Video / audio synchronization	Video and audio stream synchronization, e.g. for lip-sync.
Cost	Per-use cost	Cost to establish a connection, or gain access to a resource
	Per-unit cost	Cost per unit time or per unit of data, e.g. connection time charges and per query charges.
Security	Confidentiality	Preventing access to information, usually by encryption but also requires access control mechanisms
	Integrity	Proof that data sent was not modified in transit, usually by Means of an encrypted digest.
	Non-repudiation of sending or Delivery.	Signatures to prove who and when data was sent or received.
	Authentication	Proof of identity of user or service provider to prevent Masquerading, using public or secret encryption keys.

2.2 BoS Management

BoS management is defined in [2] as the necessary supervision and control to ensure that the desired Brilliance of service properties are attained and sustained which applies both to continuous media interactions and to discrete interactions. It can be considered a specialized area of distributed systems management.

2.2.1 Static BoS Management Aspects

The static BoS management functions relating to properties or requirements which remain constant throughout some activity are summarized in Table 3, drawing from [2].

Table 3 Static BoS Management Functions

Function	Definition	Example Techniques
Specification	The definition of BoS requirements or capabilities.	Requirements at various levels of abstraction are described as combined parameter, value, allowed variation and guarantee level descriptions.
Negotiation	The process of reaching an agreed specification between all parties.	A comparison of specifications in admission control with modification of requirements on failure, and resource reservation when an agreement is reached. The modification of requirements should consider the inter- relation of parameters and preferences of the user.
Admission Control	The comparison of required BoS and capability to meet requirements.	The available resources may be estimated with the aid of resource reservation information and performance models.
Resource Reservation	The allocation of resources to connections, streams etc.	A time-sliced model of capacity reserved is common.

2.2.2 Dynamic BoS Management Aspects

The dynamic aspects of BoS management respond to change within the environment, allowing a contract to be fulfilled on an ongoing basis. Contract specifications are often inexact as resource usage and flow characteristics are not generally completely defined in advance. The dynamic management functions are summarized in Table 4. These issues are expanded on in [2].

Most of the literature discusses maintaining a BoS contract under adverse conditions, often by reducing data volume. However, it should also be noted that BoS functions may be applied to increase data transfer rates when the system improves its ability to provide a service, i.e. a Brilliance ordered sequence of alternatives due to media scaling or renegotiation may be traversed in the directions of both improvement and degradation when BoS passes given thresholds.

Table 4 Dynamic BoS Management Functions

Function	Definition	Example Techniques
Monitoring	Measuring BoS actually Provided.	Monitor actual parameters in relation to specification, Usually introspective. Frequency of monitoring affects monitoring traffic load but reducing frequency may result in Out of specification performance for a period of time. See discussion on piggy-back monitoring with other Traffic.
Policing	Ensuring all parties adhere To BoS contract.	Monitor actual parameters in relation to contract, to ensure Other parties are satisfying their part.
Maintenance	Modification of parameters by the system to maintain BoS. Applications are not required to modify behaviour.	The use of filters to buffer or smooth streams, in order to Maintain stable delay, data rate and jitter. BoS aware Routing to maintain network characteristics. Scaling media, e.g. by modifying levels of detail provided within a stream.
Adaptation	The applications adapts to changes in the BoS of the system, possibly after Renegotiation.	Application dependent adaptation may be needed after renegotiation or if the BoS management functions fail to Maintain the specified BoS. Often achieved by media Scaling.
Synchronization	Combining two or more streams with temporal BoS constraints between them e.g. synchronization of Speech and video streams.	This involves representing each stream in a format where temporal information is stored with the data, allowing cross Referencing between the streams.

3. Brilliance of Service in Mobile Computing Systems

We shall now summarize the problems of mobility in direct relation to BoS, and then describe some of the ideas and solutions being developed specifically to manage BoS in a mobile environment.

3.1 The Impact of Mobility on BoS

One of the key differences between mobile and fixed system is that the former have to be able to adapt to the changes in BoS resulting from mobility, rather than trying to provide hard guarantees of BoS [9], [15].

3.1.1 The Effects of Link Type on BoS

Nomadic systems may connect via a local area network and then reconnect via a modem or wireless link at a later time. A wireless link is obviously needed to support mobile computing. The key considerations of bandwidth, range and cost are summarized for some popular communication technologies in Table 5.

Table 5 Common Communication Systems

Comms. System	Typical Bandwidth	Range	Costs
Ethernet Local Area Network (LAN)	10 – 1000 Mb/s	Fixed, wired network.	Infrastructure & interfaces
Wireless LAN	1 – 10 Mb/s	100 – 500 m from base station.	Infrastructure & interfaces
Infra-Red	19.2 Kb/s – 1 Mb/s	Within room.	Infrastructure & interfaces
Satellite systems	Up to 2Mb/s in the immediate future	World-wide in the future	Probably a monthly fee, Plus costs for usage. Expected to be high.
Modem via Dial-up Telephone	9.6 – 128 Kb/s	Fixed, wired network Available globally. Usually for residential and small business Locations.	A monthly fee, and / or Costs for usage. Low cost.
DECT	32 Kb/s	Cellular phone networks Approaching national coverage. Some standards differences.	A monthly fee, and/or costs for usage. High cost.
CDPD	19.2 kb/s		
GSM	9.6 Kb/s		

Wireless LAN can cover a cell of about 500– 1000m diameter while GSM (Global Systems Mobile) may cover several square km per cell but provide country-wide and international coverage through widely deployed base stations. Satellite systems may provide similar global coverage but at very high cost in the medium term future.

The use of multimedia applications requiring high data throughput is problematic for mobile systems. Whereas speech-Brilliance audio with compression requires only 8Kb/s, even low-fidelity video tends towards Mb/s data rates. In addition, it is not desirable to simply limit the capabilities of systems to the lowest common denominator. It is better to try to manage the variations in data rates of the connection due to mobility and if possible, make applications adapt to these variations. Hence, the *static* BoS management functions must support a greater range of base-line capabilities to support mobile use.

3.1.2 The Effects of Movement on BoS

One of the main problems of movement is due to hand-over as the mobile device moves from a cell covered by one base station to an adjacent cell of a different base-station during a connection. This hand-over time may result in a short loss of communication which may not be noticeable for voice interaction but can result in loss of data for other applications. Another problem is that of selecting a suitable base-station to which it can hand-over, which has sufficient spare capacity to support the connection [9]. For mobile computing, the base station may have to provide local processing, storage or other services as well as communication. A system for BoS driven resource estimation and reservation to support hand-over. Their approach is based on a connection casting a "shadow" of advance requirement on neighboring cells, where the shadow is stronger in the direction of movement.

This can be sometimes be established by including geographical knowledge of likely paths of movement. A stronger shadow represents a greater likelihood of the resource being required. The rate of hand-over may also be measured, suggesting reservation of more than one cell in advance (the cell currently occupied then casts a longer shadow of advance reservation). This gathering of information in conjunction with knowledge of the environment then allows confident predictions of future requirements to be made, enabling higher resource usage as fewer resources in the network are reserved unnecessarily. Another form of context aware resource reservation is described as, where each end of a flow is characterized as static or mobile, and advance reservations are made for mobile flows on the predicated next cell.

However, these techniques cannot completely hide all mobile link effects. Mobile wireless networks have blind spots under bridges, behind buildings or hills, where the signal may be very weak resulting in temporary Brilliance reduction or connection loss when the mobile device is in a moving car or train. Variations in link Brilliance can also be caused by atmospheric conditions such as rain or lightning. These effects require more sophisticated *dynamic* BoS management than fixed systems.

It is thus the *variation* in BoS which is the crucial difference between mobile systems and communications based on wired networks. This implies the need for adaptive BoS management which specifies a range of acceptable BoS levels, rather than trying to guarantee specific values. The BoS management is also responsible for co-operation with BoS aware applications to support adaptation, rather than insulating applications from variation in underlying BoS. The effects of mobility on BoS require then that algorithms employed must be capable of managing frequent loss and re-appearance of mobile device in the network, and that overhead should be minimized during periods of low connectivity. This is in contrast to traditional distributed applications, where reasonably stable presence and consistently high network Brilliance are often assumed.

3.1.3 The Restrictions of Portable Devices on BoS

There are a number of limitations imposed by portability of the mobile computing device [1], [4], [9]. The main limitation is in the physical size of mobile computers, as discussed below:

Mobile systems typically are designed with the limitations of batteries in mind, even where a mains power alternative is possible. Current battery technology still requires considerable space and weight for modest power reserves, and is not expected to become significantly more compact in the near future. This then places limits on the design due to the need to provide low power consumption as a primary design goal: low power processors, displays and peripherals, and the practice of having systems powered down or "sleeping" when not in active use are common measures to reduce power consumption in portable PCs and Personal Digital Assistants (PDAs). Low power consumption components are generally a level of processing power below their higher consumption desktop counterparts, thus limiting the complexity of tasks performed. The practice of intermittent activity may appear as frequent failures in some situations. Similarly, mobile communications technology requires significant power, particularly for transmission, so network connection must be intermittent.

The second point is that of user interfaces: large screens, full-size keyboards, and sophisticated and easy to use pointer systems are commonplace in a desktop environment. These facilitate information-rich, complex user interfaces, with precise user control. In portable computers, screen size is reduced, keyboards are generally more cramped, and pointer devices less sophisticated. PDAs have small, low-resolution screens which are often more suited to text than graphics and may only be monochrome. They have minimal miniature keyboards, pen-based, voice or simple cursor input and selection devices. These limitations in input and display technology require a significantly different approach to user interface design.

In environments where users may use a variety of systems in different situations, the interface to applications may then be heterogeneous, and be required to scale with available devices, in a similar manner to the network connection's scaling depending on the medium used. Ideally there should be a consistent user interface for particular applications across a range of computing devices but this is not always easy to achieve.

Whilst the limitation in battery size and power are expected to remain, I/O device technology is becoming more sophisticated: headset technology developed for virtual reality, and traditional display technology's resolution and colour representation in thin packages are areas of much development. Advances in computing power are enabling handwriting and speech based input technologies, although traditional keyboard input, and information display are unlikely to become significantly different or more advanced, due to the limitations of eyesight and dexterity of users.

BoS management in a mobile environment must allow for scaling of delivered information, and also simpler user interfaces when connecting using a general mix of portable devices and higher-power non-portable devices [1], [6]. Again the field of context aware computing provides groundwork in this area, where rather than treating the geographical context (as for mobility), one can treat the selection of end-system as giving a resource context.

3.1.4 The Effects on Other Non-Functional Parameters

Any form of remote access increases security risks but wireless based communication is particularly susceptible to undetected monitoring so mobility complicates traditional security mechanisms. Even nomadic systems will make use of less secure telephone and internet based communications than office systems using LANs. Some organizations may place restrictions on what data or services can be accessed remotely, or require more sophisticated security than is needed for office systems. In addition, there are legal and ethical issues raised in the monitoring of users' locations. However these topics are complex, application and jurisdiction dependent, so full consideration is not possible here.

Cost is another parameter which may be affected by the use of mobile communications. However, while wireless connections are frequently more expensive, the basic principles of BoS management in relation to cost are the same as for fixed systems. The only major additional complexity is created by the possibility of a larger range of connection, and thus cost, options, and the possibility of performing accounting in multiple currencies.

3.2 Current Work on Management of BoS in Mobile Environments

3.2.1 Management Adaptively

As stated in section 4.1.2, one of the key concepts in managing BoS for mobile environments is adaptation to changes in BoS. In the following we discuss three classes of change which have to be catered for, although others approach this issue with regard to transparent and non-transparent scaling of media.

Large-grained change is characterized as changes due to types of end-system, or network connection in use. Typically these will vary infrequently, often only between sessions, and thus are managed largely at the initialization of interaction with applications, possibly by means of context awareness.

Hideable changes are those minor fluctuations, some of which may be peculiar to mobile systems, which are small enough in degree and duration to be managed by traditional media-aware buffering and filtering techniques. Buffering can be used to remove jitter by smoothing a variable (bit or frame) rate stream to a constant rate stream. Filtering of packets may differentiate between those containing base and enhancement levels of information in multimedia streams e.g. moving from colour to black and white images and are similar to those in fixed network systems. However, as mobile systems move, connections with different base stations have to be set up and connections to remote servers re-routed via the new base stations. This requires moving or installing filters for these connection. A new connection may not provide the same BoS as the previous one, and so the required filter technique may differ. To manage this requires an extension of the traditional interactions for migrating connections between base stations. The selection and hand-over of control must take account of

Available BoS, required BoS, and the capacity of the network to accommodate any required filters. Where the network cannot maintain the current level of service, base stations should initiate adaptation in conjunction with hand-over [14].

Fine-grained changes are those changes which are often transient, but significant enough in range of variation and duration to be outside the range of effects which can be hidden by traditional BoS management methods. These include:

- Movement between base stations in wireless networks.
- Environmental effects in wireless networks.
- Other flows starting and stopping in part of the system thus affecting resources available.
- Changes in available power causing power management functions to be initiated, or degradation in functions such as radio transmission.

These types of change must either be notified to or negotiated with the applications concerned. as they require co-operation between BoS management and the application for adaptation [7], [15]. These effects may be seen as transient failure or loss, of parts of the system and can be similar to BoS degradation which can occur due to overload in fixed networks such as the Internet. Some notion of time-outs on quiet connections is one simple way of differentiating between failure and absence of data or connection fade, without imposing costly polling protocols on low bandwidth connections [7]. A more advanced approach may be to absorb acceptable transient losses by probabilistic or statistical BoS specifications, which will also cause downward adaptation towards failure under sustained degradation. However, speedy reaction to degradation is important, as lossy protocols manifest themselves as severe jitter, or performance not meeting specifications.

This may be achieved with techniques already developed for path adaptation, media scaling and selection, fault tolerance, and monitoring. Geographical and hand-over effects may be seen as failures lasting 1 or 2 seconds, so management systems should use a model of BoS requirements that allows them to absorb the more transient changes, and thus reduce unnecessary adaptations. Typical adaptations are likely to involve large steps in Brilliance presented to users, as storage or media scaling to many levels for data intensive streams is generally expensive. Very frequent changes in presented Brilliance may be more intrusive than small losses, or continued lower Brilliance presentation. However, it is also important that BoS management should be able to react quickly to change when appropriate – agile response to fluctuations in BoS is considered. A user-level BoS parameter can be included to describe the trade-off between stable presentation and agile adaptation. It suggests that where movement causes frequent fluctuations in service, the maintenance of BoS at a steady low level to provide seamless operation, is preferred by users. However, users whose systems experience less frequent fluctuations would tend to prefer that the BoS provided is maximized, at the expense of occasional disruption. This then may lead to a sliding scale of agility as a function of rate of variations causing adaptation. Another technique which is applicable in this scenario is to guarantee (as far as is possible) to provide a service at a basic level, and give best-effort management to enhancements.

It is common, in much of the literature, to concentrate on adaptation due to last-hop effects, as this fits the model of a mobile device with wireless link. In many situations it is a reasonable assumption that the wireless connection will determine the overall BoS. However, an end-to-end BoS management philosophy is still required, particularly for multicast systems, and those using the Internet for some part of their connection.

The impact of cost on patterns of desired adaptively also becomes more pronounced in mobile systems, where connections typically have a charge per unit time or per unit data. Adaptation paths related to BoS management should be able to describe how much the user is willing to pay for a certain level of presentation Brilliance or timeliness. The heterogeneity inherent in systems which may provide network access through more than one media will also be a factor here, as certain types of connection will cost more than others, and cost of connection may vary due to telecoms provider tariff structures.

3.2.2 Resource Management and Reservation

Some researchers contend that resource reservation is not relevant in mobile systems, as the available bandwidth in connections is too highly variable for a reservation to be meaningful. However, some resource allocation and admission control would seem prudent when resources are scarce, even if hard guarantees of resource provision are not practical. It is proposes that guarantees be made in admission control on lower bounds of requirements, whilst providing best-effort service beyond this. This is achieved by making advance reservation of minimum levels of resources in the next predicted cell to ensure availability and smooth hand-off, and maintaining a portion of resources to handle unforeseen events. The issue of resource reservation is given some consideration by those working on base-stations and wired parts of mobile infrastructures, as these high bandwidth components must be shared by many users, so the traditional resource management approach still applies a model of adaptively within currently available resources. Adaptation is divided into levels of description based on the user, the application and the system – recognizing that change may be required by the user or the system, and take place in the application or the system. A region of acceptable performance is mapped onto a region of the resource space in which adaptation can take place. Resource management is related to context awareness, discussed below, as awareness of available resources is fundamental to managing them in a heterogeneous system.

3.2.3 Context Awareness

A further aspect of resource management is that of large-grained adaptively, and context awareness. defines situation as “the entire set of circumstances surrounding an agent, including the agent’s own internal state” and from this context as “the elements of the situation that should impact behavior”. Context aware adaptation could include migrating data between systems as a result of mobility; changing a user interface to reflect location dependent information of interest; selecting a local printer or power-conscious scheduling of actions in portable environments. The BoS experienced is also dependent on awareness of context, and appropriate adaptation to that context [11]. A fundamental paper on context awareness is [13], which emphasizes that context depends on more than location i.e. proximity to other users and resources or environmental conditions such as lighting, noise or social situations. In consideration of BoS presentation, the issues of network connectivity, communications cost and bandwidth and location are obvious factors, affecting data for interactions as well as how end-systems are used and user’s preferences. For instance, network bandwidth may be available to provide spoken messages on a PDA with audio capability, but in many situations text display would still be the most appropriate delivery mechanism – speech may not be intelligible on a noisy factory floor, and secrecy may be needed in meetings with customers. “Brilliance” can thus cover all non-functional characteristics of data affecting any aspect of perceived Brilliance.

[7] proposes that protocol management should analyse connections, and adapt to make best use of the available resources. The use of Mobile IP [10] to provide location transparency for mobile hosts, and the selection between interfaces to provide the most suitable communications interface and protocol for the situation and BoS requirements. The selection between alternative network interfaces then becomes a first level of context and BoS aware resource management. An approach based on tuple-spaces, which allow time and space decoupled modelling of connections, which supports fault tolerance, mobility, heterogeneity and change in a natural manner. The use of agents acting over tuple-spaces provides the various aspects of management required, such as admission control, resource reservation, security etc. This approach then allows tuple-spaces to manage the context based variation in services received, and also smaller changes by the use of filter agents. An architecture for exporting environment awareness to mobile computing applications, based on the use of events to indicate changes.

3.2.4 Use of Standards

The International Standards Organization (ISO) and International Telecommunications Union (ITU) have a joint working group defining a reference model for Open Distributed Processing (RM-ODP). They are working on a framework for specifying BoS and its components in an ODP system, but there is no specific consideration of mobility. The Object Management Group have developed the Common Object Request Broker Architecture (CORBA) specification with vendors providing CORBA compliant platforms for implementing distributed

Systems. BoS support is to be included in the CORBA 3.0 specification scheduled for release in mid-1999. The work within the Internet Engineering Task Force (IETF) has concentrated on mechanisms to support BoS management within the internet. Some of these can be adapted to manage BoS for mobile systems.

The ODP and CORBA approaches are directed at maintaining transparency of platform, and hiding complexity from applications with respect to fixed computing devices. However [1] contends that in an adaptive, mobile environment this approach is no longer relevant. Some implementations e.g. software components previously developed for fixed network BoS architectures [7]. These systems provide adaptive connections using existing

Components, while retaining the benefits of known interfaces, and re-use of low level protocol implementations. Surveys in mobile distributed systems platforms, including a variation on the Open Group's Distributed Computing Environment (DCE), called mobile DCE. All the platforms examined (apart from Lancaster's tuple-space based platform) use remote procedure call (RPC) based interaction semantics, with relaxed synchrony requirements. However, his conclusions are that the essentially synchronous nature of these protocols are unsuitable for use under degrading network BoS, due to periods of disconnection, which is his reason for suggesting asynchronous communication via tuple-spaces.

4. Conclusions

We summarize the critical issues in managing BoS in a mobile environment, and the most interesting work relating to these issues. We consider the following to be important topics, both in existing work described in the literature, and for future development:

- The provision of context awareness, and adaptability to large-grained system dynamics, including end-system heterogeneity, and network heterogeneity. Context information must be accessible to applications to enable adaptation of BoS by user interfaces [9], [11].

- Context derived maps of resources, with resource models for BoS aware resource selection [11], [13]. Performance monitoring as input to these models to permit adaptation by BoS management [9], [13]. This enables context aware adaptation of protocols, with regard to overhead, and degree of synchrony depending on degree of connectivity [13].

- Provision for the definition of adaptation paths from user-level BoS parameters, including trade-offs, using variation tolerant specification of parameters. Trade-off should take account of meta-data relating to objects involved in requests, priority and deadline information, and available filters. BoS specification may include stability / agility and adaptation / underlying BoS effect hiding trade-off controls [9].

- Reservation without guarantees to increase confidence in the system's ability to perform tasks as required, particularly during periods of stability in the underlying BoS of the system.

In summary, much progress has already been made in providing BoS in various mobile and fixed environments. We believe that the techniques developed for BoS provision in specific environments should be brought together in a generic and flexible BoS management system so that the most appropriate methods can be deployed. Key factors to achieve this in a heterogeneous environment are the ability to define perceived BoS at the user interface level; how to relate this to underlying BoS supported within the underlying system, and how BoS aware applications can adapt. Rather than isolating mobile systems as a special case, infrastructure and applications should be able to adapt to their environment, whatever that might be.

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