Research Challenges in Future Health Care Systems*

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Abstract. Future health care systems will involve a network of heterogeneous resources providing different levels of service and will comprise of a physical and a virtual decision and control layer. The initial results presented here will lead to health care delivery with on-line decision making in order to meet QoS requirements and management targets.

Keywords: Dynamic resource allocation, cost optimisation, adaptive performance evaluation.

1 Introduction

Recent technological developments in health care include biomedical sensors, implanted medical devices, home monitoring, nurse-bots among others. Therefore it can be envisaged that any future system will require these and such disparate resources networked and integrated to provide health care services. Many scenarios have been developed to predict the future of health care systems. These future systems will need to model more than just the digital technologies that make up part of this scenario. Proper functioning of any health care system is related to the physical world that the digital technologies interact with and most importantly the human interaction which is the medical staff, administrators, other services personnel and patients who are a vital part of its functioning. This generates new research challenges which require a multi-disciplinary endeavour from all relevant research communities.

2 Research Challenges

A new mathematics that merges the digital and physical worlds will be needed to understand all aspects of future eHealth systems. These systems will need to acquire information through heterogeneous and geographically separated input sources. Management of such systems will have to integrate with the virtual layer, decision layer and the physical layer in order to achieve a set of global and/or local objectives. Some key challenges to be considered will be,

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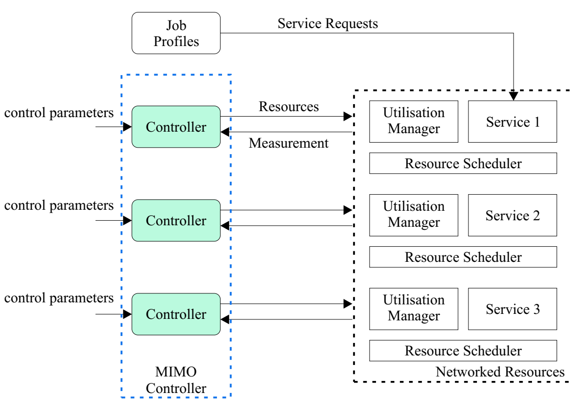
– Ability to adapt to emergent behaviour
– Ability to approximate complex systems
– Ability to merge time-based and event-based systems
– Ability to deal with systems that have both discrete and continuous components
– Ability to deal with unequal time units, where the next update time is randomly distributed
– Ability to include human interaction

The operation and control of future health care systems is therefore a complicated task and the lack of a fundamental calculus will lead to an informal and ad-hoc engineering techniques.

3 Control Theoretic Approach

Health care management systems will have high transaction volumes over varied access mediums such as the web, wireless, face-to-face contact etc., and will involve service delivery using a network of heterogeneous and limited resources. The operation and control of this system needs to be at optimum performance as determined by the service level agreements and health care policies.The ability to predict and allocate limited resources in order to meet QoS requirements at each time instant based on the feedback received of the current utilization will be a considerable advantage. The described scenario will lead to health service delivery that involves strategic decision making and provides on-line, on-demand cost evaluations based on actual and predicted service demands.

The goal will be to use a control theoretic approach to explore new performance driven architectures for automation of health care management and resource allocation tasks. This will simplify the human administrative task by



(a) Schematic of feedback control system

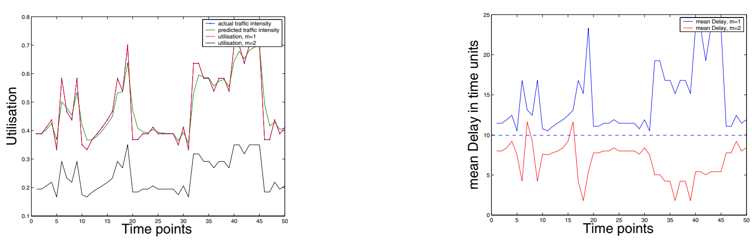
Fig. 1. Virtualised Health Services Management

providing intelligent control with optimal performance metrics that meet government targets such as cost, quality of patient care, patient treatment times, health care priorities among others. Based on control theory the main aspect of this approach is to achieve adaptation and prediction that meet service level agreements at any given time. Such a mechanism will capture and prioritise health service demands and enable services governance in a systematic way. It will also enhance the way in which information is displayed, events are correlated and filtered in order to aid in future policy development. A modelling and analysis technique which provides decision making abilities that optimise performance metrics while meeting control parameters such as policy initiatives, service priorities, cost is vital for any future eHealth system.

4 Case Study: Queueing Models in Health Care

4.1 Background

Within the research community queueing theory has been a popular approach in modelling real-world health care processes and involves waiting time and utilisation analysis, system design and scheduling in appointment systems. The distinct goals of many such analytical models has been predicting patient delay and resource utilisation, optimal resource allocation to aid decision making and reducing waiting times without greatly increasing server idleness. The main drawback of all these approaches is that they are based on offline analysis for prediction and development of static policies to meet a possible set of demands to be encountered by the system. However this approach may not be sufficient in future distributed health care systems which may require on-line, on-demand predictions and strategies to meet service and cost targets; albeit in systems with complex and/or emergent behaviour. Consider a simple example of a $M/M/m$ queue. Fig. 2 presents utilisation and service delay (response time) performance measures when the number of servers $m = 1, 2$. Though the delay is below the target of 10 time units when $m = 2$, the utilisation at the service centre is also low indicative of possible server idleness. This is not a preferred choice when resources are limited and expensive. This paper presents some promising results



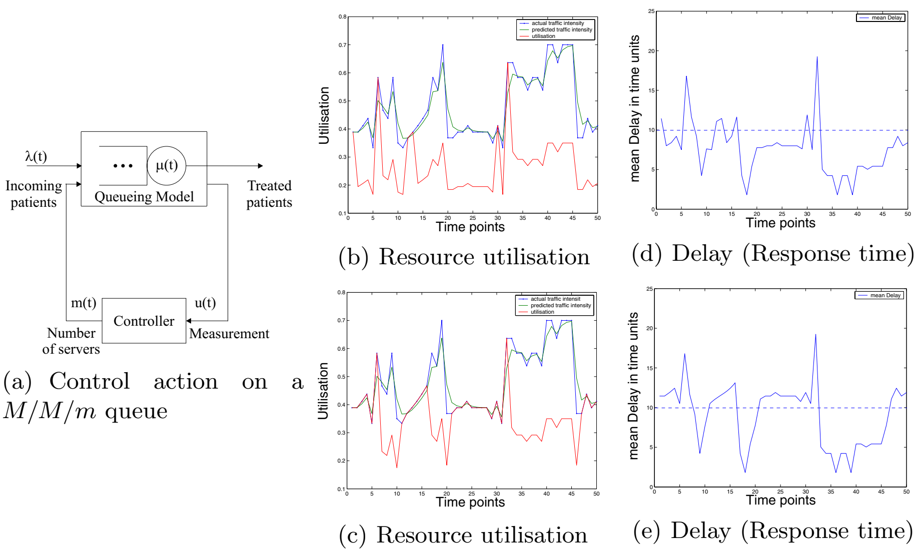
(a) Resource utilisation (b) Delay (Response time)

Fig. 2. Performance measures of a $M/M/m$ queue

in applying optimal and feedback control with queueing theory which will be a step toward achieving this objective.

4.2 Control Framework for Optimal Resource Allocation

The controller designed here use a Kalman filter to dynamically allocate server resources to the service centre based on an optimal control policy with performance index J. This approach monitors and varies resource allocation. This is achieved by the controller which tracks traffic intensity, dynamically allocates resources according to a control policy and adapts to patient arrival conditions via an on-line state estimation mechanism.



(a) Control action on a $M/M/m$ queue

(b) Resource utilisation

(d) Delay (Response time)

(c) Resource utilisation

(e) Delay (Response time)

Fig. 3. Performance measures resulting from dynamic resource allocation in a $M/M/m$ queue

For the results presented here J is defined as a function of cost of resources and penalty for missed delay targets. The cost of resources, C_r (cost units/server) and penalty cost C_p (cost units/patient) is set at $[150, 250]$ and $[200, 250]$ for Figs. 3(b), 3(d) and Figs. 3(c), 3(e) respectively. The Kalman filter enables prediction of the traffic intensity at the next sample point as shown in Figs. 3(b), 3(c). Then the optimal resource allocation (number of servers) that keeps the cost to a minimum is obtained. The optimal number of servers reduces the mean Delay as shown in Figs. 3(d), 3(e) while the utilisation at the service centre, Figs. 3(b), 3(c), is kept higher than in Fig. 2(a). This is achieved by defining an appropriate performance index J.