# Cloud Framework for Real-time Synchronous Physiological Streams to Support Rural and Remote Critical Care

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## Abstract

*We present a method for transmission and processing of real-time trans-continental medical data streams. We apply fundamentals of existing network technologies to create a secure tunnel from a remote hospital through an open-network to the Artemis Cloud. We capture and store incoming 1Hz data stream in our real-time event stream processor to allow for online real-time monitoring of the patient status. The contributions of this paper extend the Critical Care as a Service paradigm by incorporating remote monitoring centers. The results establish feasibility of the system to support real-time monitoring. However, existing protocols were required significant optimization to account for variability in throughput and availability of the network.*

## 1. Introduction

The Neonatal Intensive Care Unit (NICU) is home to some of the most critically ill infants, many of whom are challenged by complicated and life-threatening conditions. The care of these infants is in itself a complex task, where numerous medical specialists and support staffs are involved in their care. This multi-disciplinary team relies on bedside medical monitors to generate real-time information pertaining to the current status of the patient. The data produced however, can run in the thousands of hertz (Hz). The raw data used to construct the electrocardiogram (ECG) stream in some monitors may exceed 1000 Hz. Other physiological readings such as heart rate, respiratory rate, and blood oxygen saturation are generated at an average 1Hz. These heterogeneous data streams are then summarized to an hourly indicative reading and later combined with clinical data to generate evidence-informed care management strategies. The volume and heterogeneity of data, introduced by sensors presents a challenging exercise for clinicians to comprehend in full. One method to address the data requirement has been through the utilization of resources in grid and cloud computing. Public cloud offers large resource pools of processing and storage for variable needs. Security and privacy of the data stored in the cloud is a concern, however. Medical information is highly sensitive and protected by legislation. Private clouds have been of interest to address some of these privacy requirements.

McGregor (2011) proposed extensions to enable cloud computing for a real-time clinical decision support system termed Artemis [1]. There is an existing collaboration between researchers in Canada and China related to clinical research for earlier onset of Late Onset Neonatal Sepsis that has ethics approval at the University of Ontario Institute of Technology (UOIT), Oshawa; The Hospital for Sick Children, Toronto; and the Children's Hospital of Fudan University , China. In this paper, we detail an approach to enable critical care as a service allowing for real-time monitoring despite geographic limitations using the Artemis Cloud framework. By delivering critical care as a service using cloud-computing paradigms, patients in these rural and remote geographies may be monitored and cared for by specialists without the need for transport.

We evaluate the use of a secure tunnel established between the university and the hospital in China. Several observations were noted, and reflections are provided in this paper to support future work in supporting critical care as a service. This paper is divided into five sections, the second section details related work, section three introduces the case study including a description of the architecture, section four provides a discussion, and section five concludes the paper with key requirements and discussions of future work to improve the current system.

## 2. Related Work

Cloud computing has received much attention and interest from both commercial and industrial users as an alternative to in-house storage and processing of data. The increasing availability of broadband Internet connections and the reduction in cost of bandwidth has made it more attractive to move data further and in greater volume. There are several motivations for transporting data across networks. Of which, the most prominent is the ability to leverage significantly greater scales of processing power on a pay per-use for on-demand applications or reserved allocation for consistent and longitudinal processing needs.

However, there are also several concerns for the use of these increasing prevalent cloud infrastructures [2]. If the physical infrastructure were to be available for use by any interested party then, it is termed public, and when restricted, is termed private. Public clouds have been developed by large infrastructure organizations to provide consumers access to a significant common resource pools, constituting a vast number of processors, memory, and storage units [3]. However, by the virtue of their shared existence, these resource pools may prove to be a concern for organizations with significant interest in protecting sensitive information.

To address this concern, the private cloud is presented as an alternative, which is of course, with reduced scale and tailored specifically to the needs of the organization for which it is built. One of the key obstacles to pervasive use of cloud computing and remote storage of data is the attribute of Data Confidentiality and Auditability [2]. Although not practically possible in an open network for physical isolation, it can also be enforced through virtual private network; virtual machines, and middleware such as packet filters, and firewalls to create a virtual private isolation. Given open network access, Armburst and colleagues [5] assert that by the use of some well-established technologies in network security, one may achieve greater security than what can be afforded by an in-house unencrypted data store. Trends and patterns visually presented through software can allow for rapidly translating knowledge with the greatest context in the minimal time [2]. For this very purpose, there has been a long line of clinical decision support systems developed over the past few years. Most have focused on aiding the clinician with decisions involving best practices, or optimal therapy given predefined generic conditions [6]. Many real-time health applications have sprung up, particularly in offering monitoring via body area sensors or through the sensors embedded in mobile ‘smart’ devices [7]. These devices primarily offer the ability to capture and perform initial processing in order to display the physiological data. The Artemis framework, shown in Figure 1 has been demonstrated as a real-time event processing engine consuming data generated by XML output (Figure 2) of the physiological sensors to perform real-time analysis to classify and predict clinical conditions. Artemis Cloud is an extension proposed to demonstrate Artemis as a Software-as-a-Service (SaaS) and Data-as-a-Service (DaaS) [1]. The contribution of this paper is the method by which we show how physiological data secured by SSL VPN site-to-site connections can be utilized in order to enable real-time remote monitoring and analytics to support rural and remote critical care around the world.

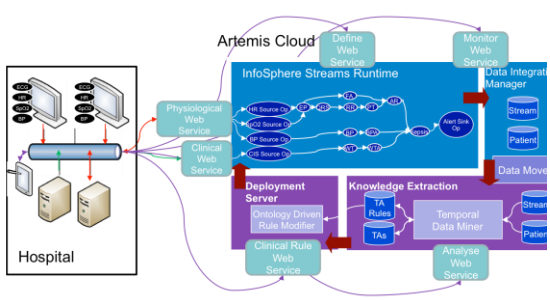


**Figure 1:** Framework of the Artemis Cloud [3]

## 3. Case Study

An instance of Artemis Cloud has been deployed on secure servers at the University of Ontario Institute of Technology, which is behind a firewall, and acts as the client initiating the SSL VPN connection. The neonatal intensive care unit at Fudan Hospital has 4 bed spaces that were enrolled in the study, for six days of monitoring commencing from the 29th of January and lasting till the 4th of February. These beds were connected to the *Physiological Web Service* provisioned by the CapsuleTech software, which enabled service-based access to the device.


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<?xml version="1.0" encoding="UTF-16"?>
<DataCaptor ID="{81E88426-493A-4C89-B462-F0F36E6FF4I
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</TimeStamp>
</Identifiers>
</DDI>
</DataCaptor>
```


**Figure 2**: Template extract of the incoming physiological data stream output from DataCaptor.

**Oxygen Saturation (SPO2)**

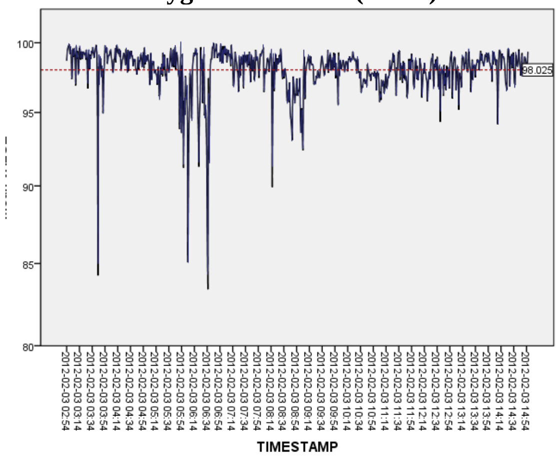


**Figure 3**: Oxygen saturation values over a 12-hour period, mean value (98.24) showing normal saturation.

**1 Hz SPO2 Stream Mapped over 72 Hours**

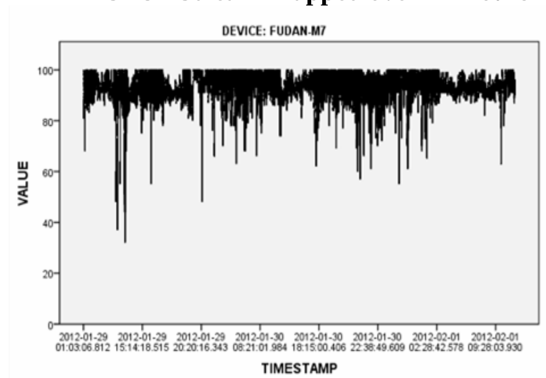


**Figure 4**: Oxygen saturation values over a 72-hour period, showing fluctuations between 35-100% oxygen.

Using the Artemis Cloud, the participant hospital can participate with a thin client model enabling the connectivity to the medical devices and enabling the secure transmission through the physiological web service component. In this case study we adopt a client-server instance called DataCaptor by CapsuleTech to facilitate the physiological data. The server is deployed within the private network of the hospital network, behind firewall, and collects heart rate, respiratory rate, and blood oxygen saturation among other readings from four bed spaces at 1 Hz. Once the data has been sampled at the bed side, it is prepared in XML format and sent over a secure SSL VPN link that connects Fudan Hospital to UOIT.

A Virtual Private Network (VPN) enables a host computer to send and receive data across the Internet as if it were a private network with all functionality and security of the private network. The private connection is made using the Secure Sockets Layer, which establishes an encrypted link between a web server and browser. Patient identifiers are changed to before leaving the hospital network to ensure patient anonymity at UOIT. The physiological web service then forwards to the data acquisition module implemented in IBM InfoSphere Streams 2.0. During this initial pilot only the online analysis timing and sequencing of messages components were tested. The arrival of data and quality of that data were the primary metrics for the performance of these experiments. The Streams Runtime ensures that packets are time stamped in proper sequence for any analysis modules that may use the physiological streams. The data is then sent to the Data Integration Manager module and written to a DB2 database for persistent storage.

Artemis Cloud allows for real-time remote monitoring of the streams via the secure monitor web service. This is used to display the raw data, any alerts or notifications, or a combination of both. An example of displaying near real-time $SpO_2$ readings from a remote hospital is shown in Figure 3. Periodic updates regarding the throughput and quality of connection are sent via email. While it is the Streams Runtime that is responsible for analyzing data as it comes, the algorithms are derived from input gained from consultation with domain experts. This enables powerful retrospective analysis on patient data over multiple time frames. Figure 4 shows a sample extrapolation of mean SpO2 of a patient over four days. It also shows various drops in saturations and subsequent recoveries. Events of significance are examined and algorithms for detecting such events are detailed in Thommandram et al, 2013 [10]. The Deployment Server takes the coded algorithms derived from the knowledge extraction phase and pushes them back into the Streams Runtime in order for Artemis Cloud to detect events in real-time.

## 4. Discussion

A secure connection to the locally positioned real-time analytical engine was demonstrated through this research. However there were some challenges that needed to be addressed to ensure a stable connection. The SSL VPN service was contingent on several infrastructural limitations. The throughput was variable throughout the week as the load of the network infrastructure locally and remote were in peak, and substantially increased during the end of the week (Friday-Sunday). While the throughput was variable, it resulted in intermittent timeout to the connection, requiring the client system at UOIT to reinitiate the session. When sessions were terminated, it required

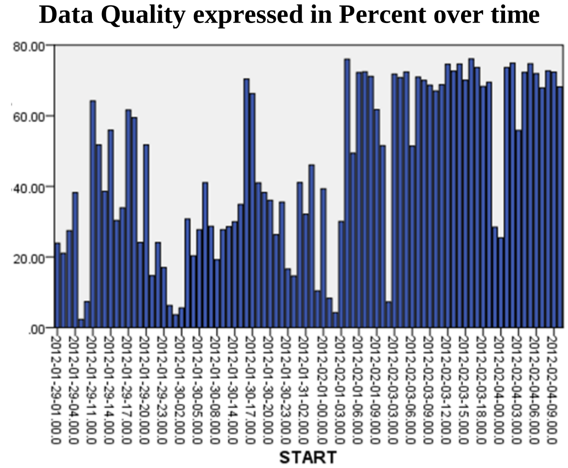


**Figure 5**: Sample of SPO2 values taken in real time from a medical monitor located in Fudan over 72 hours

physical intervention, as the client could not be configured for automation. We then measured the data quality achieved by aggregating all data samples into hourly ranges, and enumerated by each day. The data quality rate of higher than 2000 hourly samples of SPO2 generated at the bedside at 1 Hz frequency generating a maximum total of 3600 hourly samples per bed. From Tuesday – Thursday, the data quality was observed below 50%, and went as low as 36% for short period of time. During the end of the week, from Friday – Monday, this number was in excess of 80.95%. With the instantiation of the SSL VPN configuration, we have demonstrated a secure platform to receive high fidelity physiological data from bedside monitors in Fudan. Based on these observations three requirements are produced.

1. Optimize by encoded output: large overhead can be detrimental to real-time communication
2. Automate failover: buffer data and attempt to reestablish the link upon any disconnect.
3. Common synchronization parameter: avoid use of system clock as default synchronization.

These three observations served to inform several iterative connections as well as substancial modifications to future version of on-line real-time transfer of high frequency data.

## 5. Conclusion

As a powerful analytical center for health data, the Artemis Cloud allows for a tightly integrated real-time platform to deliver secure and timely critical care. Patients located anywhere along the web-enabled open network can connect and transmit synchronous streams of physiological data which can be consumed by the event stream engine to deliver insightful recommendations of the patients dynamic health status for specialists located in urban care centers. In addition, it addresses the growing need for providing accessible and affordable healthcare to the most vulnerable populations in rural and remote communities around the world. As future work, we plan on examining and evaluating alternative VPN configurations to improve reliability of the incoming data stream throughout the entire duration, as well as introducing fast wave data streams which includes frequencies of up to 1000 Hz in real-time.

## 6. Acknowledgement

We would like to thank Wenjie Zhang, and Dr Xiaoling Ge at the Chidren's Hospital of Fudan University for their assistance with the project. This research is supported by an NSFC-CIHR China Canada Grant.

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