Visualization of Passively Extracted HL7 Production Metrics

Ricardo Ferreira[1], Manuel Eduardo Correia[1], Francisco Rocha-Gonçalves[2] and Ricardo Cruz-Correia[3]
[1]*INESC - Instituto de Engenharia de Sistemas e Computadores do Porto, Rua Doutor Roberto Frias, 4200-465 Porto, Portugal*
[2]*Instituto Português de Oncologia do Porto, Rua Dr. António Bernardino de Almeida, 4200-072 Porto, Portugal*
[3]*CINTESIS, Faculty of Medicine of University of Porto, Al. Prof. Hernâni Monteiro, 4200-319 Porto, Portugal*

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Abstract: **Introduction:** The improvements made to healthcare IT systems made over the past years led to the creation of a multitude of different applications essential to the institutions daily operations. **Aim:** We aim to create and install a system capable of displaying production metrics for healthcare management with little requirements, efforts and software providers involved. **Methods:** We propose a system capable of displaying production metrics for healthcare facilities, by extracting HL7 messages and other eHealth relevant protocols directly from the institution's network infrastructure. Our system is then able to populate a knowledge database with meaningful information derived from the gathered data. **Results:** Our system is currently being tested on a large healthcare facility where it extracts and analyses a daily average of 44,000 HL7 messages. The system is currently capable of inferring and displaying the daily distribution of healthcare related activities such as laboratory orders or even relevant billing information. **Conclusion:** HL7 messages moving over the network contain valuable information that can then be used to assess many relevant production metrics for the entire facility and from otherwise non-interoperable production systems that, in most cases, can only be seen as black boxes by other system integrators.

1 INTRODUCTION

The development of new information technologies and its rapid adoption by healthcare institutional facilities has paved the way to the rise of eHealth as a mature research discipline. EHealth technologies are currently transforming healthcare facilities by revolutionizing the way they produce and process useful business information. This allows them to improve their service efficiency, reduce internal costs and more importantly help to provide better service to its patients (Kreps and Neuhauser, 2010; Blaya et al., 2010). This type of developments are strongly backed up by governments searching to invest in ways to improve their healthcare systems and at the same time reduce their maintenance costs (Black et al., 2011; Catwell and Sheikh, 2009).

Recent investments made in eHealth have also promoted the development of many Hospital Information Systems (HISs). These technologies have been crucial in helping deploy tools such as the Electronic Health Records (EHRs), Picture Archiving and Communication Systems (PACSs) or even electronic prescription systems. While there is undergoing research to evaluate the real impact of these new technologies in healthcare systems (Schweitzer and Synowiec, 2012; Catwell and Sheikh, 2009), their everyday usage has already left hospital facilities with many different, sometimes incompatible systems, each playing a different role in the everyday activities at the healthcare facility

With each different system, healthcare facilities are also left with a big amount of heterogeneous data scattered throughout its HISs. Moreover, important data such as application logs, can also be considered as an important source of metrics to assess the good functioning of the healthcare facility.

It goes without saying that this data can be used to deduce meaningful information and trends about the daily activities of the healthcare institution and how their Information Technlogies (IT) systems are working. That is, suppose one of the deployed systems is used to schedule medical appointments. We could easily use the system's logs to try and identify the number of appointments scheduled during a certain period of time. Such hypothesis when generalized to a

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considerable number of different systems, could easily produce significant data that could be then used to build a knowledge database from which meaningful performance metrics for healthcare could be easily produced.

In order to build such a knowledge database we would need to develop a system capable of extracting the log files produced by the HISs. However, this approach presents some difficulties. For once the data used to build the database would be highly dependent on the quality of the log files produced, and the extraction system would need to be able to interact with all the different relevant systems present in the healthcare facility that are involved in the business process being analysed. In this paper we propose a system capable of extracting meaningful data by sniffing packets exchanged between the different systems present in the network infrastructure and build a meaningful knowledge database of performance metrics with the collected data.

Towards this goal, we take advantage of the integration techniques typically employed by healthcare facilities to promote interoperability amongst their heterogeneous systems. By directly analysing network IP packets carrying Health Level Seven (HL7) messages, our system is capable of extracting meaningful data and build a knowledge database rich with meaningful indicators about the healthcare facility. Based on that same database, our system is then able to produce a series of charts that can be used to support more informed decision making by the upper levels of management.

The remainder of this paper is organized as follows. Section 2 provides a background review for several systems and methods aiming to assess healthcare production levels. Section 3 includes a system description of the methods we use to assess hospital productivity levels from information directly collected from relevant data streams on the network. Section 4 presents and discusses the results thus obtained by a system deployment on a large Healthcare institution. Lastly Section 5 concludes the paper and presents future work and improvements we want to do with our current system implementation.

2 BACKGROUND

2.1 Performance Assessment

Measuring hospital facilities performance in a comprehensive way and as a as whole is nowadays critical for proper health care management. The ability to fully comprehend the expected and real production level of a given healthcare facility throughout time is instrumental to support informed decision making and to identify opportunities for informed business processes improvements to the quality of care and the service provided. Current academic literature offers an extensive overview of several studies on the topic of management metrics and their assessment for healthcare facilities, that aim to effectively qualify and quantify hospital performance under many different dimensions. According to the United Kingdom National Audit Office (National Audit Office, 2010), there's a thin line separating the terms hospital productivity and efficiency. According to the document's authors, productivity should be considered as the relationship between the inputs and outputs of healthcare facilities. On the topic of assessing productivity levels, Solà and Prior (Solà and Prior, 2001) use a Data Envelopment Analysis (DEA) model in order to obtain productivity levels for Catalan hospitals and a Malmquist index in order to produce an overview of productivity evolution over time. Linna in (Linna, 1999) claims there's a direct relation between technological investment and increases in hospital productivity. Barros et al. (Barros et al., 2008) uses a Luenberger indicator in order to assess the productivity in Portuguese hospitals. Chag et al. (Chang et al., 2011) introduce an interesting relation between the increase of hospital productivity levels and efficiency improvements in their own services.

2.2 HL7 Standard

In order to try to solve the interoperability problems being felt in healthcare facilities, developments were made in order to advance and adopt medical IT standards for those type of services (Barbarito et al., 2012; Yuksel and Dogac, 2011).

One of the main standards employed for interoperability in medical IT infrastructures is the HL7 standard (De Meo et al., 2011). The development of HL7 began in 1987 by an American National Standards Institute (ANSI) accredited organization whose main goal, among others, was to implement a standard for the management of patient data that could be easily used by heterogeneous healthcare systems as a way to exchange data in more meaningful ways (Eichelberg et al., 2005).

Currently, version 2 of the HL7 standard is the most employed version among healthcare facilities worldwide (Eichelberg et al., 2005). When employing HL7 V2, the content of each message is encoded in ASCII, the standard also allows for the creation of a certain level of flexibility on what type of information passes on the HL7 segment fields. As a result, many fields are allowed either to contain loosely formatted information or no information at all. Although this type of flexibility can sometimes be desirable, when used without care, it can sometimes invalidate interoperability between different systems and therefore jeopardize the main intent for why HL7 was initially created. In order to rectify this situation, the new HL7 version 3 standard now uses a Extensible Markup Language (XML) language with a much more precise syntax and semantics.

2.3 Healthcare Integration Engines

Assuming the existence of a standard for message exchanged in healthcare IT infrastructures, the integration between heterogeneous systems can then be promoted in two different ways. Either the sending system communicates directly to end receiver using a message standard or an integrating engine is introduced at the healthcare facility in order to interconnect several different otherwise incompatible systems.

In the first case, the usage of a message standard such as the HL7 may not be sufficient to assure that heterogeneous systems can exchange information. Such challenge arises due to the fact that even if software vendors in an healthcare facility both use HL7 as the message standard in their applications, they will hardly agree on the specific message and semantics format to use(Corepoint Health, 2010). In practice, it is extremely difficult to implement an end-to-end integration model that encompasses all software vendors within an healthcare facility.

To allow different legacy systems to interconnect, healthcare facilities often employ interface engines(Corepoint Health, 2010) to solve interoperability issues between systems even if they use the same message exchanging standard. Interface engines are deployed as an intermediary between different systems.

3 PROPOSED SYSTEM ARCHITECTURE AND IMPLEMENTATION

3.1 Overall Architecture Infrastructure

Our system is composed by five different nodes that work independently of each other. Figure 1 depicts the overall interactions between the five different system components. They are:

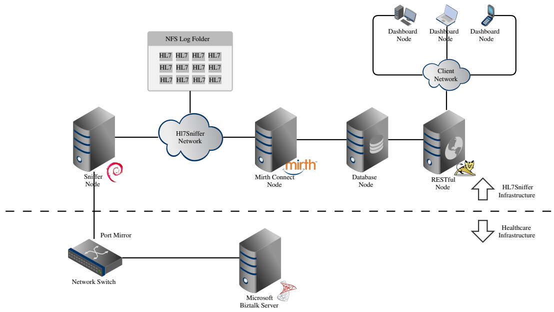

Figure 1: System Infrastructure.

- **Sniffer Node.** Responsible for passively extracting IP network packets from the network, reassemble HL7 messages and then store them in log/data files, making them available for further processing by using the Network File System (NFS) protocol.
- **Integration Engine Node.** Reads the log files produced by the “Sniffer Node”, extracts a set of predefined fields from the HL7 message and stores them in the “Database Node”.
- **Database Node:** Stores all the meaningful data extracted from each HL7 message gathered from the network infrastructure.
- **Representational State Transfer (RESTful) Node.** Receives Hypertext Transfer Protocol (HTTP) requests and responds to the clients with information fetched from the database. In a general way, this node acts as a proxy for our knowledge database and aims to hide from the client the complexity of having to query the “Database Node”
- **Dashboard Node.** Requests information from the “RESTful Node” and display a set of highly interactive charts with the information that is being compiled at the knowledge database.

Our initial goal aimed at developing a system for meaningful performance metrics extraction of Healthcare business processes that maintained a maximum level of independence from the healthcare information systems infrastructure and their respective system vendors and developers. That being the case, the institutional network where the data being produced by all the healthcare facility systems flows, presents a perfect opportunity to get hold of that information in a complete independent and transparent way. We can achieve this by placing efficient data packets collector sensor nodes at some strategic points within the healthcare facility network. This gives us a birds eye view of all the data that is being exchanged by the healthcare institution and is simply accomplished by the use of network packet sniffing techniques to extract a very accurate real time image of the information that flows within the institutions networks.

3.2 Data Collection

To extract all the HL7 messages destined to the hospital integration engines, we have used and modified the *tcpflow* tool. This particular tool extracts and re-assembles Transmission Control Protocol (TCP) packets directly from the network, at the same time that it creates a series of log files with the data contained in each packet payload.

One of the most attractive features of *tcpflow* is its ability to reconstruct and log the data transmitted in TCP connections without having to maintain all the data from each packet in memory. Instead, *tcpflow* uses the machine Hard Disk Drive (HDD) to write each packet payload directly on the correct position of the log file. However helpful, the *tcpflow* was subject to some alterations in order to fulfil certain objectives such as:

- Create a new log file at each new TCP stream;
- Indentify the beginning of each HL7 message;
- Timestamp each captured HL7 message;
- Close the log file when a TCP FIN packet is detected;
- Close the log file when it contains a given amount of HL7 messages;
- Close the log files of inactive TCP streams;
- Move all the closed files to a given directory of the system.

3.3 Data Analysis

An integration engine typically serves as a connector between different otherwise incompatible eHealth systems. Namely, this tool allows different applications that use the HL7 standard to communicate with each other by applying transformations to the HL7 messages that are necessary for data to be transferred in a meaningful way between those applications.

In our monitoring infrastructure, for our "Integration Engine Node" we used an instance of the Mirth Connect engine, an open source software typically employed by healthcare institutions as a connector between different heterogeneous systems. However in our scenario, the Mirth Connect engine plays a much simpler role, its main use is to read each of the log files produced by our modified version of *tcpflow*, extract the necessary metrics according to the type of each HL7 message and insert that data into the “Database Node”. We thus configured a Mirth Connect server with a series of channels each of which acts similarly to a pipeline, where each channel routes, transforms and/or extracts some data from each HL7 message. Our main goal in adopting this strategy was to have a single channel with the responsibility of polling all log files previously generated by our system, queue them and then send a copy of each HL7 message present in that file to a series of different channels where each one of them would do a specific function to the message. We then take advantage of concurrency by having each Mirth Connect channel running on separate threads and therefore we can a take real advantage of multiprocess systems.

3.4 Dynamic Performance Metrics Management and Comparisons Throughout Time

For our system to be able to display useful information about the level of performance of a given healthcare institution we firstly needed to find a reliable base of comparison for each metric. That is, suppose we are evaluating the number of medical appointments performed on a given day, in order to understand if the current metrics are within the expected ranges,

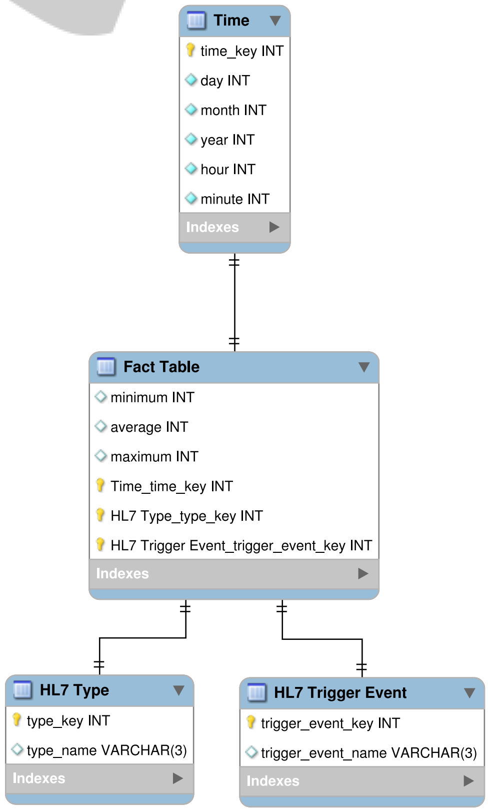

Figure 2: Fact Table Structure.

Table 1: Datawarehouse Data.

HL7 MSG Type	Day	Period	Nr. Messages
ADT-A16	1	09:00 - 10:00	112
ADT-A16	1	10:00 - 11:00	154
...	...	...	...
OML-O21	3	22:00 - 23:00	8
OML-O21	3	23:00 - 00:00	3
...	...	...	...

our systems first needs to have a reference value that provides a base of comparison for the number of expected appointments on a given day.

In order to obtain the previous requirements, we decided to apply some data warehouse techniques to the database containing all the captured data. By doing so, our system is able to deliver meaningful information much more quickly by keeping a set of useful pre-calculated metrics separated from the main database.

Figure 2 presents our fact table structure. For the dimension fields, we used the time of capture, the HL7 type and trigger event fields of each message and finally for the measure fields we used the minimum, average and maximum number of messages.

Table 1 presents an example of the kind of information our datawarehouse holds. By structuring data in this form, we are able to maintain an accurate representation for the number of messages our system should expect to receive at any given time of the day.

3.5 System Aditional Usages

The systems' architecture also presents a great value as a starting point for the creation of several other parallel and independent services. Namely, by using an infrastructure similar to the one presented in Figure 3, we are able to use our Mirth Connect Node as a source for HL7 messages exchanged at the facility and thus open the possibility of having several different systems using the gathered messages in order to provide other types services.

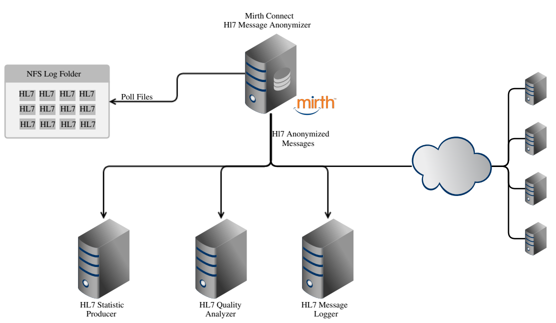

Figure 3: Mirth Network.

For instance, a service that could assess the semantic and syntactic quality of the HL7 messages exchanged at an healthcare institution or even a service that dynamically searches for incoherent or erroneous data present the HL7 messages. An even more elaborate system that can be built around this system architecture, is a patient registry system directly populated by the Mirth Connect node, that is capable of encompassing all the patients currently "active" at a given hospital. Such system could even include information related to the pathologies and courses of treatment the patient is currently undertaking, provided that this information flows in the network being monitored by the packet sensor nodes.

One actual problem that such an integration model could help to resolve, resides with the fact that each HL7 message may contain susceptible information about patients of the healthcare infrastructure and as such, the disclosure of such information may be considered a severe breach of privacy. By using a network of Mirth Connect engines similar to the one presented in Figure 3 we are able to create an anonymization channel capable of removing any type of sensitive data and proceed to send the anonymized HL7 message to a given set of different destinations, therefore guaranteeing that the next nodes do not receive any kind of patient sensitive data.

The proposed system can also be seen as an opportunity for the creation of an integration system completely independent of any software vendor. Assuming our system is able to collect all HL7 messages associated with a given software vendor, since we use an instance of the Mirth Connect engine, our system would be able to read those same messages and create a channel capable of applying any type of transformation the hospital services would require, therefore eliminating the necessity of having software vendors altering their own channels in order to fulfil a specific institution requirement.

4 RESULTS

On a daily basis, we have processed an average of 44,000 HL7 messages with an average rate of 932 messages per minute, reaching peaks of 1,200 messages per minute on critical hours of the day. Since the start of the data collection process on the 26th of April 2014 until the 28th of June 2014, approximately 1,300,000 HL7 messages were successfully extracted from the network by our Sniffer Node.

Table 2 shows the number of messages received on a typical working day, grouped by the HL7 type and *trigger event*. The number of messages refer-

Table 2: Message Types Daily Results.

Description	Number of Messages
Laboratory Order	18,318
Observation Message	6,869
Appointment Rescheduling	5,363
New Appointment Booking	4,563
Pending Discharge	2,484
Appointment Cancellation	454
Financial Transactions	316

ring to laboratory orders represents 30% of the total HL7 message traffic in the healthcare infrastructure, followed by observation messages (15%) and laboratory order acknowledgements with 14%. The type of HL7 message least seen on the network refers to the cancellation of appointments (1%) and lastly the messages containing billing information (0.7%).

4.1 Graphical Results

Figure 4 presents an example of the charts our system is able to produce. The shadowed area represents the range of expected messages on a given time frame while the black curve is calculated by querying the main database to retrieve the number of HL7 messages received in the current day.

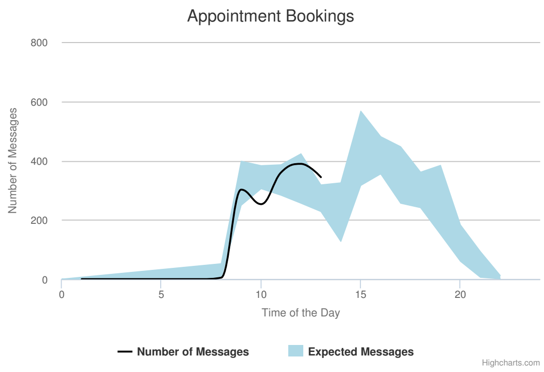

Figure 4: Chart Sample.

Figure 5 shows the results obtained when we compare the number of medical appointments scheduled during the different days of the week.

Apart from providing an high level vision about the performance of several hospital services, the data our system gathers can also be used to provide a much more specific view about the individual performance of hospital staff. Since HL7 messages often carry information related to specific individuals working on the institution, our system can gather that information and thus calculate several metrics that can possibly be used to rank individual performances.

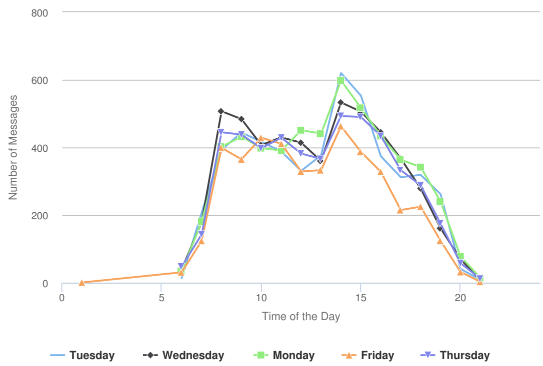

Figure 5: Day Of the Week Comparison.

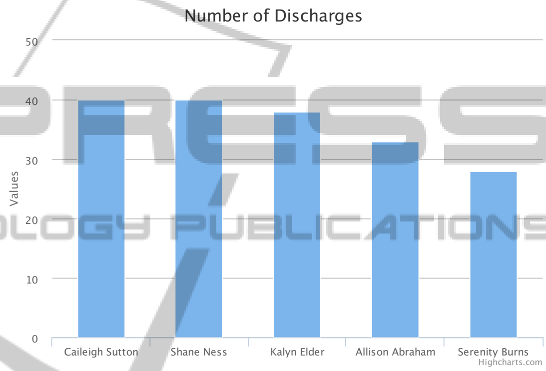

Figure 6: Individual Performance.

Figure 6 presents the number of patient discharges issued by the hospital physicians. As we can observe, by presenting metrics in this form, we can quickly assess and compare individual performances and therefore use such information to build a performance rank.

From a service monitoring point of view, the proposed charts can be used to identify potential malfunctioning services when for instance, the number of messages either drops or grows too much outside their expected range. By using such approach we lay the groundwork for the creation of an alert system based on the number and type of HL7 messages flowing through the network. Such an alert system could easily support different levels of severity based on the level of discrepancy from the expected number of messages.

As from an administrative point of view, the information gathered can potentially be used in order to assess the production level at individual levels and at different data dimensions. For example, by taking advantage of some types of HL7 messages containing data that can uniquely identify an individual in the healthcare facility we believe that our system would be capable of producing information related to the performance levels at an individual level.

5 CONCLUSION

The improvement of the healthcare IT infrastructures has led to the creation of multiple applications aiming to provide physicians and healthcare institutions with the necessary tools to improve their individual performance and level of care. These systems are highly heterogeneous and are responsible for the creation of big pockets of data that end up being scattered throughout the healthcare infrastructure.

Such pockets of data contain very valuable information that could be put to further use, for example they could be employed to assess the levels of performance of each healthcare infrastructure at different levels, ranging from the institutional level to the professional performance of each individual healthcare professional. It all depends on the quality and detail of data that is being produced and flowing within the institution information systems. However helpful this information may be, very few hospitals are really prepared to take advantage of every source of potential piece of information the IT infrastructure produces. As such, every day valuable information ends up being lost before it can be properly analysed and integrated into some useful business metric.

We believe that our system takes one step further and allows healthcare institutions to recover such pockets of data and put them to good use by producing very useful overall statistics about daily basis activities of the institution as a whole that would be otherwise very difficult to determine.

We have described and implemented an architecture for a system capable of incrementally building a knowledge database for an healthcare facility based on standard protocol messages transmitted through the network. We were able to efficiently extract HL7 messages directly from the network with the additional advantage of not having to depend on physical memory in order to reconstruct out of order packets since we use the information contained in TCP headers in order to calculate the precise point where each piece of data fits in the content and use this information to write packet collected data directly to the hard disk. This allows us to process very long data streams in a very efficient way.

We have been able to use the collected data mainly for two different goals. From a monitoring point of view, the data gathered can be used to find normal levels of activities performance for a given healthcare facility and with that information, one can easily detect outliers that result from malfunctioning sections of the healthcare infrastructure. A deeper analysis of this data can also be used to support decision makings from an administrative point of view.

We have also described a set of other uses for our system architecture. Namely, after the message extraction from the network, one can also build a network of systems that could receive anonymized HL7 messages and produce, for example a new service based on the data received such as HL7 semantic and syntactic quality assessment.

5.1 Current Limitations

In terms of hardware, the system is heavily limited by the processing capabilities of the Sniffer node at several levels. That is, starting on the Network Interface Card (NIC), we believe our overall system would greatly benefit from the usage of a hardware capable of automatically associate each packet with an extraction timestamp directly calculated from hardware (Agarwal et al., 2003). With this, the cost of timestamp association with each message could be greatly reduced since in our current implementation, such timestamp can only be calculated in user space.

Apart from the NIC on the sniffer node, one could also benefit from using a CPU capable of offering more computational power in order to reduce the amount of time each packet needs to remain in user space to be analysed. Also from an hardware point of view, the usage of Solid-State Drive (SSD) hard disks could also improve the overall performance of our sniffer node, since the TCP stream reconstruction is made directly on the hard drive in order to reduce amount of physical memory needed.

From the software point of view, the current deployed version of our system is unable to deal with fragmented IP packets. As for now, our system simply discards any packet fragmented at the network layer. Tests have already been made in order to provide the Sniffer node with the capability to reconstruct fragmented packets, however, the reconstruction of such packets proved to be too slow when using the hard disk.

Finally, related to the actual quality of the information our system allows to take directly from the network of the healthcare institution, the accuracy of the extracted metrics may be compromised if many correction messages are exchanged through the hospital network. Nevertheless, if this happens, our system should be able to detect this behaviour and therefore flag it as an unoptimized way for the institution to work.

5.2 Future Work

As future work, we want to concentrate our efforts in supporting more healthcare standards and be able to draw significant information based on the collected data. The support for different standards should enable us to empower our knowledge database with sufficient data to produce more well grounded statistics with more incisive views on several business processes.

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