# A MODEL OF INTELLIGENT PACKET SWITCHING IN WIRELES COMMUNICATION NETWORKS

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***Abstract***

*A fuzzy Logic-based methodology was adopted in this thesis for the optimization of packet switching in wireless communication systems. To accomplish this, the major factors associated with packet switching were identified and investigated. The factors investigated were: transmitted packet length (TPL), packet loss (PL), packet arrival rate (PAR), traffic intensity (TI), and latency (L) or delay. The thresholds for these factors were established using data collected from an existing organization: The Akwa Ibom Broadcasting Corporation (AKBC) – a Third Generation (3G) Government owned company, operating in Uyo. The collected data and standards were used to establish the necessary thresholds at par with established standards, which served as inputs to the fuzzy logic inference engine. A total of 243 rules were constructed to drive the respective membership functions which linguistic terms were formed using the established threshold, to discern knowledge into the system. An extensive simulation of the rule set was then carried out to determine the optimal solution. Results obtained from the simulations showed that the overall throughput (crisp output) of the optimized system outperformed the existing system, even at average performance of all the parameters investigated. Indeed, when the traffic got bustier, the existing system crashed compared to the optimized system which sustained the throughput at about 81% during peak periods of high transmission rate. Further, the optimized system exhibited quality performance even when most of the parameters operated poorly, to preclude unnecessary wastage of system resources and keep the system under normal operational conditions. However, the throughput of the optimized system dropped when some of the parameters exceeded the recommended thresholds. In practical systems, this constraint is necessary to avert a loop forever network in the presence of severe network degradation. The interactive effect of some of these factors on the overall network throughput was also investigated. It was discovered that they also followed similar trends, revealing the strong dependence or correlation of one factor on the other.*

**Keywords:**

## 1. Background of the Study

Corporations, businesses, banks, government agencies, medical establishments, and educational and research institutions are now relying heavily on distributed information applications for storing, transporting, and accessing data, for distributed computing, for telemetry and remote control, and for communicating by audio and visual media. Communication networks therefore provide the transport infrastructure that carries the information flows between such distributed information applications. The communication network is built from the tools of communication links and information, covering geographical distance by being carried over such links (Sethi and Sarangi, 2017). The design and fabrication of such links involve the consideration of electromagnetic propagation in various media, transducers, modulation schemes, error-control coding, and physical interfaces. Modern communication networks are largely digital and the information they carry is transported as digital data; hence the term data communication networks. From the viewpoint of communication network engineering, or networking, the communication links is simply viewed as imperfect bit-pipes, the imperfection being that the bit-pipes can delay, lose, or modify the information they carry. It is widely assumed that, for reasons of efficiency, the various communication networks (e.g., Internet, telephone, TV, radio) will merge into one ubiquitous, packet-switched network that carries all forms of communications (Lee, Park, Park and Kang, 2012). This view of the future is particularly prevalent among the Internet community, where it is assumed that packet-switched IP is the layer over which everything else will be carried (Jo, Kim, Lee, Kangasharju and Mülhäuser, 2017); that is why packet switching is becoming vital in today's communication systems.

Fundamentally, network models are constructed by defining the statistical distribution of the arrival and service rates in a queuing system that subsequently determine these attributes. But, the vague and imprecise nature of most of these attributes renders statistical simulation obsolete and calls for an intelligent approach. Hence this Thesis will adopt a fuzzy logic approach to imprecise data – to manage packet-switching services in wireless communication networks. First, we identify inherent factors (or inputs) that are contributory to packet switching (i.e., packet length, packet loss, packet arrival rate, traffic intensity and latency). Second, analytical models are developed to model the performance of the inference system. Third, a fuzzy controller with if…then rules is built to drive the system, given a set of constructed membership functions from the input linguistic terms. The output of the system is the network throughput – a performance metric that measures the amount of data moved successfully from one place to another in a given time period.

## 2. Statement of the Problem.

All Information Technology team faces complaints indicating that the network is slowing down or delivering applications poorly. What comes immediately to their mind is the verification of network performance factors (i.e., latency, packet loss, Packet arrival rates, traffic Intensity and Transmitted Packet length etc.).

Nevertheless, the network is not the sole driver of data transfer speed and of the end-user experience.

Many other factors directly impact how fast application queries and responses will flow through the network. If one wants to troubleshoot performance degradations, this checklist of the factors that can badly impact the transfer speed will come in very handy.

**(i) Network latency**

Network latency refers to the time needed to send a packet from the source to the destination. This time varies depending:

- on the physical distance, the number of network devices which have to be crossed (also referred to as the number of hops)

- and to a lesser extent, to the performance of each of the devices.

The relationship between latency and transfer rates depends on the protocol that carries the data. Maintaining our focus on the most common ones: for a UDP (user datagram protocol) flow, latency may not have an impact. As for TCP applications, typically the most commonly used protocol, it will have a drastic impact. And because of this enabling technologies are therefore required in order to support the challenges of PSN.

**(ii) Network congestion**

Network congestion refers to the saturation of a path used by packets to flow between the source and the destination. The element on the path can be either an active device (e.g., router or switch) or a physical link (e.g., cable).

When the maximum capacity of the element is reached, the packet cannot be transferred in a timely manner as it is either put in a queue (e.g., in a router) or dropped if a no queue system is available to retain them. It may even become impossible to set up new sessions.

The consequence will then vary, depending on the level of delay generated by the congestion: Packets are delayed for a short period of time. The latency will increase, some retransmissions will occur (for TCP flows) as the acknowledgment packets are not received fast enough by the sender. Duplicate acknowledgment packets will also be received, Packets are lost or dropped (packet loss).

The retransmission increases significantly: as packets are not acknowledged, they will then be massively re-sent. Disconnections: sessions are dropped as too many packets are lost.

Random models are inappropriate as there is no structure for intelligent forwarding algorithms to exploit. Real systems must be built, measured, and learned from in order to make progress on this most important facet of PSN.

**(iii) Infrastructure parameters (QoS, Routing)**

Although the overall network path is free of any congestion (lack of bandwidth or system resources), some devices apply policies:

- Prioritization: some traffic is either more strategic (critical applications) or more performance sensitive (real-time applications, VoIP, video conferencing) and gets allocated a higher priority than the rest of the applications using a given network path. In case the maximum capacity on the network path is reached, lower priority flows will start experiencing retransmission, packet loss or disconnection depending on how long and important the congestion is.

- Routing/load balancing: some devices distribute the load across a group of servers/devices or route the traffic to an adequate path from a performance and/or an economic standpoint. The devices may also be overloaded or misconfigured which could lead to retransmission, packet loss or disconnection issues.

- While troubleshooting slow transfer rates, it is important to list the devices on the path between clients and servers. You can then identify at which point in time and for which flow: retransmissions, duplicate acknowledgments, packet loss, TTL (Time to leave) expired and session time-out or incomplete TCP start can be observed.

As a result of the above mentioned challenges an intelligent system must be developed that will enhance effective Packet switching in the wireless communication Networks

## 3. Analysis of the Existing System

The case study for this research is the AKBC (Akwa Ibom State Broadcasting Corporation) – Star-time digital Transmission. Figure. 9 Shows a unified Universal Mobil Telecommunication System (UMTS) architecture of the existing system, and is split into two sections namely:

(i) Service Monitoring Model for UMTS Packet Switching (PS) network, and
(ii) Network topology of trail UMTS PS network

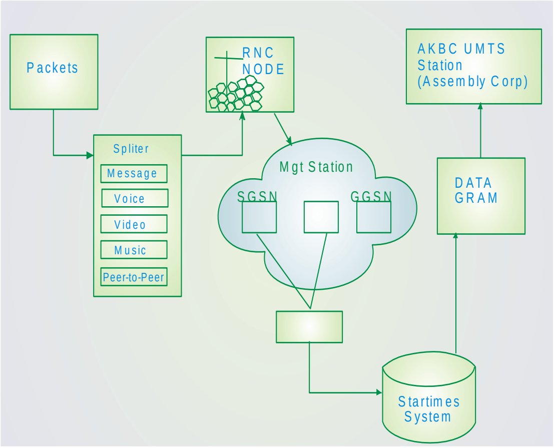

Fig. 1: A unified UMTS architecture of the existing system, Source (ABKC)

## 3. Service Monitoring Model for AKBC UMTS PS Network

The AKBC Star-time transmission uses a UMTS PS data transmission method. The UMTS Packet Switched (PS) network is a typical data network in which data traffic, particularly with streaming media services, is live, extremely time sensitive to delay, latency and jitter, non-tolerant to congestion. For example, a small minority of packet service subscribers running FTP, streaming video or peer-to-peer (P2P) file sharing applications can generate enough traffic to congest UMTS PS networks and impact the majority of subscribers using interactive Web browsing and e-mail applications. In the past, network operation and maintenance was focused more on monitoring the entire throughput. The UMTS PS model for service monitoring is capable of monitoring and capturing the necessary Key Performance Indicators (KPIs) data at the service level in addition to the network level. In the model, various types of service packets enter PS core domain via the Iu-PS interface, the entry port of SGSN (Serving General Packet Radio Service Support Node). After the encapsulated tunnelling transport between SGSN and GGSN, the packets are delivered out to external network via the exit Gi interface in GGSN (Gateway General Packet Radio Service Support Node). Hence the data monitoring starts from interface Iu-PS, the entry port of SGSN, and ends in interface Gi which is the exit of GGSN. The monitored KPIs for the model include two types of parameters: *QoS performance parameters and service parameters*, the former includes delay, jitter, packet loss, throughput, and utilization; while the latter is the *throughput* of all types of services going through the SGSN and GGSN. Fig.10. depicts the service model of the UMTS PS network integrated for performance monitoring. Different from traditional instant network monitoring, the UMTS PS model for service monitoring achieves:

(i) long run view of the PS service the user is experiencing;
(ii) service-level quality and performance metrics affected by the traffic as well as vendors equipment (SGSN and GGSN);
(iii) correlation of fault and performance data captured over a long period to identify the potential service affecting outages;
(iv) consolidated utilization and performance data that can be applied for future network expansion planning.

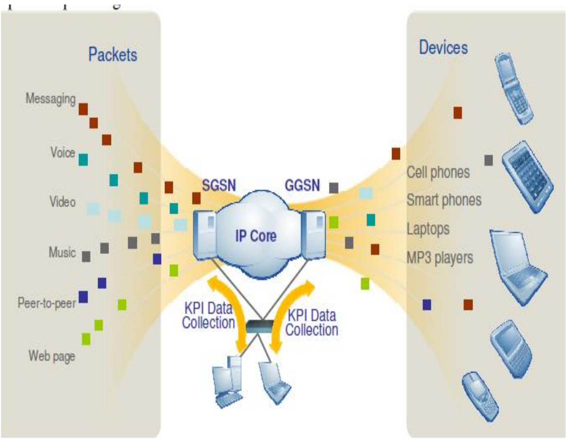

**Fig.2. UMTS PS Model of Service Monitoring, Source (AKBC)**

Fig.2. is composed of a SGSN which connects with radio network via Iu-PS interface and a GGSN which accesses Internet and Intranet of Enterprise 1. Firewall and Network Address Translation (NAT) are built between UMTS PS network and external networks. The radio network domain consists of a Node-B (Base station) and a Radio Network controller (RNC). The network administrator monitors the network traffic through management station with authorities to access the network entities (NEs) of UMTS PS network. The objective of this is to monitor the throughput interface Gi (Eth1:100) as it leaves GGSN.

## 4. Network Topology of Trail UMTS PS Network

The services are randomly triggered by a service/call generator tool in lieu of RNC, Node B and wireless terminals. The tool stores large quantities of historical traffic samples from a certain mobile operator A’s network environment. Hence the tool in our case is actually a substitution of radio domain to simulate the real network environment of the mobile operator A. The simulated traffic generated by the tool is stochastically delivered into SGSN via Iu-PS interface and further transported through packet switched domain. The whole simulation process is no difference with a real network environment from traffic monitoring aspect. The performance parameters and service parameters are monitored as outputs based on the simulated traffic of services generated by the service generator. If this model is applied in a real environment, the monitored data will be the monitoring results based on the real traffic generated and delivered from radio domain. Five key performance indicators (KPI) are recorded as the network QoS parameters: Latency, GGSN average loading (Utilization), throughput in Eth1:100, packet loss in interface Gn (192.168.0.11) between GGSN and SGSN, and packet loss in interface Gi (Eth1:100 IP address: 192.168.0.12) between GGSN and external network. The management station collects the KPI data in 20 continuous sample periods (1 hour as 1 sample period). The sample data round up to fifth places of decimals after unit conversion from per hour to per second are recorded in the table in the ***appendix B.*** This recording however, is scaled a sample of 1 hour as 1 sampled period for 20 days selected at random in a month for the period of three months of March, April and May 2016.

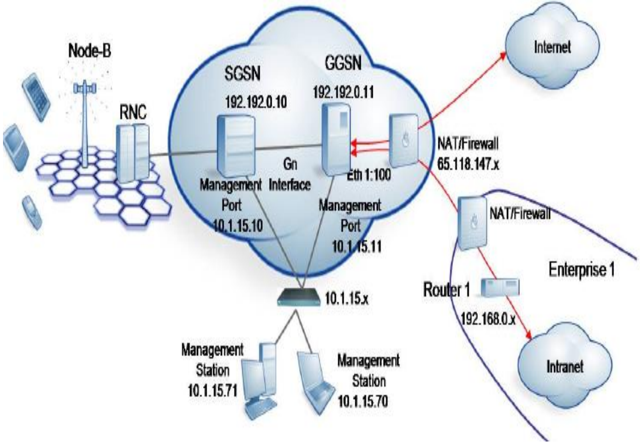

**Figure .3. Network topology of trail UMTS PS network, Source (AKBC)**

The AKBC-Star Times network used the six parameters enumerated below: Delay, Jitter, Packet Loss, Throughput, Latency and Utilization with SGSN and GGSN as monitoring devices. In their model, various types of service packet enter PS core domain via Iu-PS interface, the entry port of SGSN (Serving General Packet Radio Service Support Node). After the encapsulated tunnelling transport between SGSN and GGSN, the packets are delivered out to external network via the exit: Gi interface in GGSN (Gateway General Packet Radio Service Support Node). Hence, the data monitoring starts from interface Iu-PS, the entry port of SGSN, and ends in interface Gi which is the exit of GGSN.

## 5. Research Methodology

The proposed system is fuzzy logic-based, and uses membership functions to define the threshold values for each metric. A set of rules is also defined for each metric to guide the optimization process. Fuzzy logic is tolerant in imprecise data, nonlinear functions and can be mixed with other techniques for different problems solving. A fuzzy logic-based methodology is exploited in this Thesis for effective packets switching in the wireless communication Networks. The Fuzzy Inference System (FIS) is a popular methodology for implementing fuzzy logic. FISs are also known as Fuzzy Rule-Based Systems, Fuzzy Expert Systems (FES), and Fuzzy Associative Memories (FAM). The FIS procedure used in this research is presented in Fig. 4.

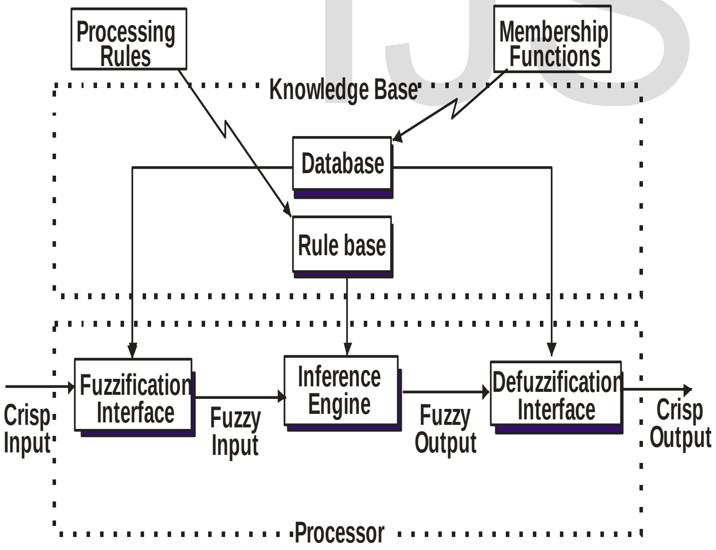

**Fig.4. FIS procedure**

The FIS consists of the knowledge inference and processing stages. The knowledge-base provides the membership functions (MFs) and fuzzy rules required by the processor. In the processing stage, numerical crisp variables (linguistic variables) are the input to the system. These variables are transformed using the MF of each variable into a set of fuzzy-like parameters which serves as inputs to the Inference Engine. The fuzzy input is further transformed by the rules of the inference engine to a fuzzy output. These linguistic results are then converted by a defuzzification stage into numerical values that become the output of the system. The Mamdani FIS has been the most commonly used in simulation. A Center of Gravity (COG) approach for the deffuzzication process is used in this research work

## 6. The Proposed System Framework

The proposed system framework defines the methodological workflow for achieving the desired fuzzy logic system. The framework as shown in Figure 5 consists of three phases: Conceptual model and system architecture development, Fuzzy Inference System (FIS) design and implementation, and System optimization and prediction. During the conceptual model and system architectural development, data are gathered from the existing system and analysed, to ensure good understanding of the existing system. Application of the systems analysis and design steps are applied as shown in section 3.1, to discover the problems of the existing system. Based on this discovery, analytical models depicting the existing system are then constructed. An optimal feedback model is then derived for the efficient building of the system model architecture. The constructed analytical model will be used to generate existing system prototypes for model testing during the optimisation and prediction phase.

In phase 2, the Fuzzy Inference System (FIS) that drives phase 3 (the optimisation and prediction phase) is designed and implemented. In this phase the MATLAB interface defining the fuzzy-based model is designed, followed by the input and output membership functions, and then the respective fuzzy rules. At the end, these rules are integrated into the FIS for efficient optimisation and prediction of the system.

In phase 3, both the existing and optimised systems are simulated and evaluated to allow for efficient decision making that guarantee an improved system. Here prototypes of the existing and new system are simulated and compared to evaluate the level of improvements. The crisp solution serves as the required predictor for comparison, where quality decisions regarding the existing system's performance can be taken. A detailed description of components of the various phases is discussed in the following subsection, as well as Chapter Four.

## 7. Data Collection

Data used in this Thesis were collected from the control room of the Akwa Ibom State Broadcasting Cooperation (AKBC), Uyo – Akwa Ibom State. Our concern is on efficient packet switching, and the features investigated include the transmitted packet length, packet loss, packet arrival rate, traffic intensity, and transmission time delay/latency. Averages of the data collected from the control room were computed and is summarized in Table 1..

Table.1: Averages of input data collected

| Parameter | Value (range) |
|---|---|
| Transmitted packet length | 1752 - 2304 (kb) |
| Packet loss | 1.24 - 2.96 (Mbps) |
| Packet arrival rate | 2.13 - 15.00 (ms) |
| Traffic intensity | 10.5 - 30.0 0 (bps) |
| Latency | 0.00012 - 0.30 (ms) |

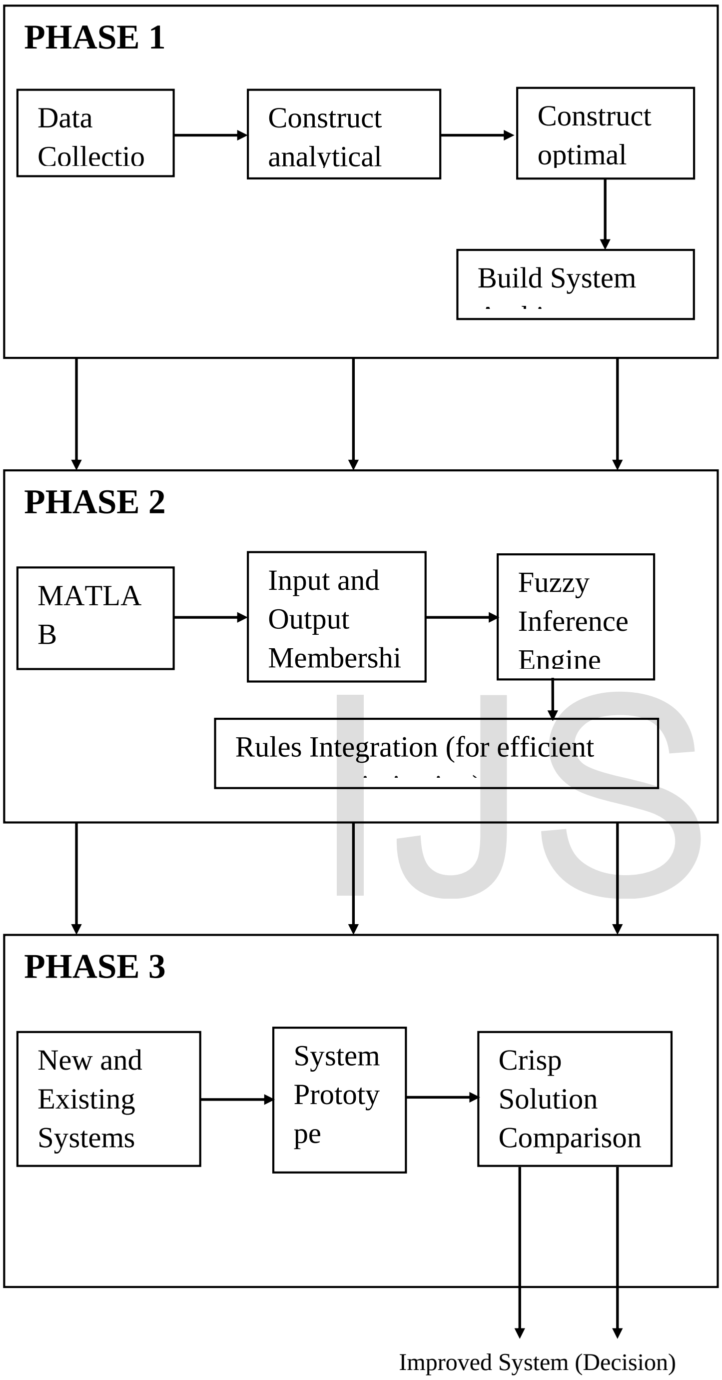

Figure.5: Proposed system framework

These input data constitute the linguistic variables of the fuzzy logic system and were used to develop the membership functions.

## 8. SYSTEM MODEL

The architecture describing the fuzzy inference process of the proposed fuzzy logic-based process is shown in Figure. 6.

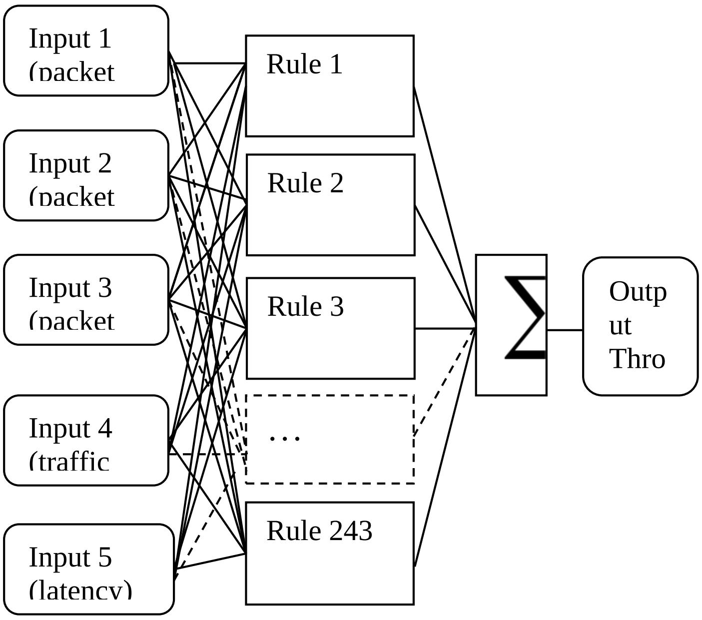

Figure.6: System model architecture describing the fuzzy inference process for the packet switching system.

In Figure.6, the inputs are crisp (non-fuzzy) numbers, limited to a specific range (in the universe of discourse of the input variable). These inputs are classified to determine the degree to which they belong to the appropriate fuzzy sets (linguistic terms) through membership functions. They are then evaluated (in parallel) by a set of constructed rules (a set of IF-THEN statements), from the set of decomposed linguistic terms defined using fuzzy reasoning by the membership functions describing the call drop control features. The results of the rules are further combined and distilled (defuzzified) using the membership functions. The membership functions are used to map the non-fuzzy input values to fuzzy linguistic terms and vice versa. They quantify the membership terms to yield a crisp (non-fuzzy) output (number). Five linguistic variables were identified as input to the fuzzy logic system (FLS). These variables enumerate the parameters/features used for determining the efficiency of the call drop control system. In our case we have {Transmitted Packet Length (TPL), Packet Loss (PL), Packet Arrival Rate (PAR), Traffic Intensity (TI), and Latency (L)}.

## 9. Discussions

Packet switching is very essential for the optimization of the available bandwidth in a network, to minimize the transmission latency, and to increase robustness of communication. While circuit switching was a natural choice for voice only networks, it cannot handle bursty traffic efficiently. With increasing amount of data usage happening on the access network, packetisation and packet switching has become absolutely essential to support such bursty traffic. Packet switching has always excelled at handling messages of different lengths, as well as different priorities, providing good quality of service (QoS). However, packet switching was designed for data.

Telecommunication networks are experiencing dramatic increase in capacity demand, mostly related to the exponential take up of the Internet and associated services. To support this demand economically, transport networks are evolving to provide reconfigurable optical layer which, with optical cross-connects, will realize a high-bandwidth flexible core. In addition to providing large capacity, this new layer is required to support new services such as rapid provisioning of an end-to-end connection under customer control.
The development of technologies such as Voice over Internet Protocol (VoIP) means that packet switching can now be used to transmit voice traffic as well as data. This can have large cost benefits for businesses, as it means that they do not need to install separate packet switched networks for their data and circuit switched systems for their phones. Using packet switched technology for voice traffic also confers many of the robustness and scalability benefits seen by packet switched data traffic to the phone network. Today, using the IP protocol, packet networks are becoming faster, cheaper, and more ubiquitous. In the near future, packet networks may likely replace circuit-switched networks nearly everywhere, since with proper QoS guarantees, voice, video and other low latency applications can travel as effortlessly as data applications over such packet networks.

## 10. CONCLUSION

Optimal packet routing has been widely studied for various networks. This Thesis considered the optimization of packet switching using the throughput measure. An approximate reasoning approach adopting fuzzy logic was implemented to solve the packet-switching problem, such that the communication network can maximally utilize the allocated bandwidth. To obtain an adaptable system, real-life empirical data were obtained from an existing 3G network, where membership functions were constructed using averages of each parameter, and scaled for optimization purposes. Five parameters that directly influence packet-switching were considered for the purpose of predicting the optimum performance of the network. These parameters were, transmitted packet length, packet loss, packet arrival rate, traffic intensity and latency.

In designing the Fuzzy Inference System (FIS), fuzzy rules were built using the AND logic – an approach that guarantees interactions between the respective fuzzy parameters or variables. A simulation of the existing system was then carried out, and its performance compared with an optimized version of the proposed system. Results obtained revealed that the optimized system outperformed the existing system, and is recommended to improve the existing system performance of AKBC.

## 11. CONTRIBUTIONS TO KNOWLEDGE

This Thesis has made modest contributions to knowledge, as follows:

(i) The application of discrete solutions has often been adopted in analytical studies for ease of tractability. However, previously reported results obtained for heavy traffic may be misleading by indicating delay reductions. As demonstrated by our results, an intelligent approach using fuzzy logic is therefore important to maintain good system performance and improve the existing system. This Thesis has designed a robust system with useful parameters to optimize the functions of an existing system;

(ii) For practically relevant non-heavy traffic, there are some differences between the switch (network) settings, which become complicated for heavy traffic. Through approximate reasoning and numerical solutions, this Thesis has been able to prove the efficiency of fuzzy logic in packet switching. The proposed system has contributed to reducing packet losses caused by increased traffic, hence, improving the throughput performance, and most suitable for practical systems;

## 12. RECOMMENDATIONS

In modern communication networks, particularly in packet-switched networks, routing is an important process that has a significant impact on the network’s performance. Ideal routing algorithm comprises finding the “optimal” path(s) between source and destination router, enabling high-speed data transmissions and avoiding packet losses. This Thesis therefore recommends the following:

(i) The existing system should adopt a robust routing strategy, since routing is most important in any communication network. The Fuzzy Logic system developed in this Thesis can offer seamless routing of packets, and in a controlled manner;

(ii) The objective of a routing strategy is essentially to minimize the mean delay of the packets in a network, subject to some reliability or capacity constraints. With the high capacity and intense communication nature of AKBC, the proposed system offers minimal latency and low packet losses, and is reliable for implementation and seamless transfer of packets in the existing network;

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