PARSIMONIOUS TRAFFIC-DESCRIPTOR FOR QOS ROUTING DECISIONS IN BLUETOOTH NETWORK

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ABSTRACT

Traffics from real-time, high-speed, multimedia, and interactive applications are bursty and are known to associate with self-similar property. It has a direct impact on network performance. Link characteristics may also contribute to the network performance, particularly when routing decisions are to be made at a router node to select its forwarding link. Therefore, if the source traffic and the link quality can be precisely characterized for resource allocation and reservation at the time of routing, a better level of QoS guarantee could then be granted to user applications in a resource-limited Bluetooth ad hoc network. However, the problem lies in the formulation of a mathematical model that can incorporate least possible parameters but well describing the application requirements, such that efficient and reliable QoS routing decisions are achieved. Thus, this work aims to develop a parsimonious *traffic-descriptor*, which will be used intermediately for resource reservation and ultimately for QoS routing decisions at a router node. The performance of the traffic-descriptor is observed through a Matlab simulation. It was found that the traffic-descriptor has described the source traffic and the link quality with fairly good precision.

Keywords: bursty traffic, self-similar, Bluetooth ad hoc network, traffic-descriptor, quality of service.

1. INTRODUCTION

When ubiquitous computing and last-meter connectivity are to be implemented, Bluetooth ad hoc networking may be well suited to be deployed [1]. The applications for that computing and connectivity may include personal area networking (PAN), wearable computing, sensor networking, and mobile gaming. However, in executing one of these applications, routing decisions at several intermediate router nodes may have to be performed as depicted in Figure 1.

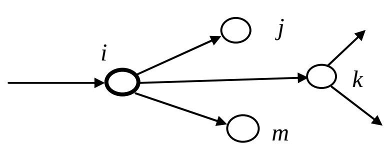


Figure 1. Routing decision at a router node

A sender or a router node *i* is to make a routing decision to select a forwarding link based on certain criteria, such as bit rate of the link, *BER* value of the link, and distance of the link. A mapping between the characteristics of the link with that of the demands of an application is then performed onto the three available outgoing links. The selected link not only has to fulfill the requested demands but also to provide certain degree of service guarantees to the requesting application. However, in nowadays complex and sophisticated application scenarios, there are multiple Quality of Service (QoS) parameters that need to be satisfied simultaneously. In order to accommodate these requirements, adaptive resource allocation strategy is normally employed, where negotiation is performed between the demands and the availability of the resources. Through a feedback mechanism, resources that have been reserved for an application may have to be adjusted according to the new requirements. For this reason, the selected forwarding link may only provide an optimal solution. The final result shall be an optimal usage of the limited resources but providing efficient and reliable QoS routing.

However, Bluetooth network is well known for its limited resources, where the bandwidth is scare and the transmission power is low [2]. Therefore, providing QoS in Bluetooth ad hoc network is a great challenge, particularly with respect to service guarantee that it can offer to the requesting applications. In its simplest form, QoS can be defined as the ability of satisfying user requirements [3].

Apart from the forwarding link criteria, the characteristics of the source traffic may also affect the efficiency and reliability of the QoS routing decisions. Generally, traffic of real-time, high-speed, multimedia, and interactive applications from web browsing, audio/video conferencing, video-on-demand, forecasting, sensoring, on-line transactions, and multiparty games are bursty [4]. In its simplest mathematical form, burst is defined as a ratio of peak bit rate and mean bit rate [5]. In many cases, burst can be triggered from rare events, for example, a transfer of large file size as compared to average file size. As determined by [6], bursty traffic is normally associated with self-similar property, in which the traffic performance measure is difficult to obtain. This leads to a situation where QoS is hard to achieve, since the traffic's characteristic cannot be precisely described to Resource Manager for resource allocation and reservation. As a result, bursty source traffic may have a direct impact on network performance and in QoS provisioning to user applications.

Therefore, if the characteristics of the forwarding link and the source traffic are to be described to Resource Manager, a traffic characterization process is needed, by which a *traffic-descriptor* will be produced. That is, a traffic description of the forwarding link and the incoming traffic is used to provide QoS routing decisions at a router node. Simply, resources are allocated and reserved according to the characteristics of the link and the traffic stream. Some other features of the network may also be considered.

However, the problem lies in the formulation of a mathematical model that can parsimoniously incorporate all but least possible parameters of the network environment so that the QoS requirements of an application can be embedded into the traffic-descriptor. In particular, Token-Bucket (TB) scheme with its parameters are commonly used to develop a traffic-descriptor for resource allocation and reservation [4]. However, not all of the TB parameters are suitable to be used or not all are needed. This may require the usage of external non-TB parameters.

Hence, the objective of this paper is to develop a parsimonious traffic-descriptor, which has only least parameters but well describing the system in question. For this purpose, a mathematical model that measures level of burstiness α, degree of self-similarity H, and quality of the forwarding link must be developed. By using this so-called deterministic information, the QoS provisioning at the time when resources are to be allocated/ reserved to the requesting application and at the time when routing decision is to be made to select a forwarding link would then be more accurate and guaranteed. However, the resource allocation and reservation procedures are not within the scope of this paper; it should be given to Resource Manager. Thus, this work is limited to only providing a traffic description for Resource Manager to use.

The rest of the paper is organized as follows. Section 2 discusses the behavior of self-similar property and explores its characterization procedures. Section 3 explains the methodology used to derive a traffic-descriptor and its parameters, and followed by a simulation. Results and analysis from the developed traffic-descriptor are presented in Section 4. Finally conclusion is made in Section 5.

2. RELATED WORK

This section discusses some works that have been done by others with respect to mathematic of burst and traffic characterization process.

2.1 The Mathematic of Burst

The phenomenon of self-similar property in a bursty traffic stream was first discovered by Leland and his team from Bell Lab in 1994 [7]. It provided evidence that inter-arrival times for burst packets in local area networks (LANs) were actually following a heavy-tailed distribution of power law. Their study on Ethernet LAN traffics from 1989 to 1992 has established that self-similar (or fractal) property in a traffic stream could not be captured by conventional traffic models. Supported by [8], it was confirmed that packets' inter-arrival times have deviated away from exponential distribution, such as Poisson. One simple type of heavy-tailed distribution is Pareto distribution. Apart from the inter-arrival times, the other factors that could lead to heavy-tailed distribution are file size, burst duration, and ON/OFF period [6]. Additionally, a work by [9] has proved that variable bit rate of MPEG video traffic is also exhibiting self-similar property.

On an ad hoc network, Bluetooth implements Segmentation and Reassembly (SAR) protocol at L2CAP layer, in which long message blocks received from upper layers are segmented into smaller packet sizes of types DMx or DHx (M – Medium, H – High, x = 1, 2, or 3 slots) [10]. As a result, segmentation on frames may produce a number of packets, which may follow a heavy-tailed distribution. Thus, it can be projected that the Bluetooth's SAR protocol execution on MPEG video data may produce heavy-tailed distribution with respect to some of its features. A research work by [11] has identified that the total number of packets produced by SAR on each video frame is following a heavy-tailed distribution. This has confirmed that bursts of traffic are always having fractal property. However, to describe the heavy-tailed distribution and its self-similar property, second order statistics is required.

Heavy-tailed distribution is defined as follows [12]. Let X be a random variable with cumulative distribution function (cdf) of $F(x) = P(X \le x)$ and complementary cumulative distribution function (ccdf) of $\bar{F}(x) = 1 - F(x) = P(X > x)$. A distribution $F(x)$ is said to be heavy-tailed if

$$\bar{F}(x) = P(X > x) \sim cx^{-\alpha} \qquad (1)$$

when $x \to \infty$ for positive value c and $0 < \alpha < 2$. In other words, a distribution is heavy-tailed if ratio of $P(X > x)/x^{-\alpha}$ is approaching 1 when $x \to \infty$ for $\alpha > 0$. The asymptotic form of the distribution is following power law. One of the simplest heavy-tailed distribution is Pareto with probability distribution function (pdf) of $f(x) = \alpha k^{\alpha} x^{-\alpha-1}$, where $\alpha > 0$, $0 < k \le$ x. Accordingly, the distribution has respectively cdf and ccdf of

$$F(x) = P(X \le x) = 1 - (k/x)^{\alpha} \qquad (2)$$

$$\bar{F}(x) = P(X > x) = (k/x)^{\alpha} \qquad (3)$$

where α is a shape parameter and k is a scale parameter. A value of α is also measuring the burstiness level in the traffic stream.

The mean for Pareto distribution is expressed as $\mu = \alpha k/(\alpha - 1)$ and its variance is expressed as $\sigma^2 = \alpha k^2/(\alpha - 1)^2(\alpha - 2)$. If $\alpha < 1$, the distribution would have infinite mean; if $\alpha < 2$, the distribution would have infinite variance; if $1 < \alpha < 2$, it would associate with finite mean and infinite variance; and if $\alpha \ge 2$, both mean and variance are finite. In general, if the variance of the Pareto distribution is infinite, then X would associate with high variability in its distribution, thus bursty.

One important property of a heavy-tailed distribution is that it is self-similar, as have been proved by [7] and supported by [13]. Self-similarity is defined as follows [15]. Let $X(t)$ be a wide-sense stationary time series with mean μ, variance σ^2, and autocorrelation function $\rho(\tau)$. Let $X^m(t)$ be a newly derived time series from $X(t)$ by averaging a number of m non-overlapping block sizes. Its aggregated series is

$$X^m(t) = (m^{-1})(X_{tm-m+1} + X_{tm-m+2} + \ldots + X_{tm}) \qquad (4)$$

and $\rho^m(\tau)$ is its autocorrelation function. A process $X(t)$ is said to be self-similar if

$$\rho^m(\tau) = \rho(\tau) \quad \text{for } m = 1, 2, 3, \ldots \qquad (5)$$

Simply, the time series is look the same when viewed at different time scales. As claimed by [14], superimposition of several independent of ON/OFF heavy-tailed traffic sources is just enough to produce a self-similar traffic stream. Therefore, bursty traffic would contain self-similar property in the stream.

2.2 The Traffic Characterization

A work by [6] provided evidence that self-similar property has direct impact on network performance. Also, as identified by [7], if it is known that the source traffic is bursty, two definite consequences might occur: the increase in buffer requirement and the longer delay experienced. Therefore, it is important to identify the degree of burstiness α and the level of self-similarity H in the source traffic stream. If these can be determined, a specific control mechanism could be employed to smooth out the traffic burstiness. To achieve this, traffic characterization process is normally used [4].

Combined with some other features of the traffic and/or the system, such as efficiency of the source packets and link quality [17], the QoS requirements of an application can be more accurately characterized and described to Resource Manager. This requirement is stated as a traffic description in a form of a *traffic-descriptor*. In this way, much better resource allocation and reservation could be made, and a more deterministic network performance could be obtained. Subsequently, the QoS can be granted to users with certain degree of confidence.

To characterize source traffic, Token Bucket (TB) scheme may be used in a 2-in-1 combined function as discussed in [4]. The first function is to regulate the arriving bursts to a more controllable and deterministic form of traffic flows. The second function is to characterize the incoming traffic so that a traffic-descriptor is produced. However, TB scheme alone may not be able to completely describe the source traffic and the network environment. Therefore, other components are required to work with the TB. The expected result shall be of more accurate allocation and reservation of network resources onto the selected forwarding link at the time when routing decision was made.

There have been a number of works done on the production of a traffic-descriptor, which normally expressed as (*r*, *b*). Papers by [17] and [18] elaborate the production of the traffic-descriptor using the TB scheme. However, work by [19] has suggested a traffic-descriptor of the form (*r*, *unlimited*), which the bucket size can be as big as possible. However, as determined by many queuing systems, such as work of scheduling in [20], the bigger the bucket size the longer the delay experienced. Study by [4] could be the best piece of work that takes into account the self-similar property of the source traffic for QoS routing decisions, which the others previous works did not.

3. METHODOLOGY

This section proposed a system model used for the development a traffic-descriptor, discussed the source traffic, and explained the simulation environment.

3.1 The System Model

Figure 2 represents a system model of a sender or a router node, at which a routing decision is to be made to select its forwarding link from a number of available outgoing links. At the input point before submission to Token Bucket (TB) scheme, the SAR protocol accepts frames and segments them into smaller DMx or DHx packets. TB is used together with a Transmission Controller (TC) to produce a traffic-descriptor, which will characterize the source traffic and the forwarding link, and to forward the information to Resource Manager. This is done as an effort to obtain efficient and reliable QoS routing decision at a router node.

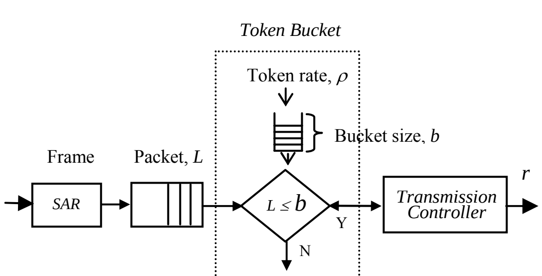


Figure 2. The system model of a router node

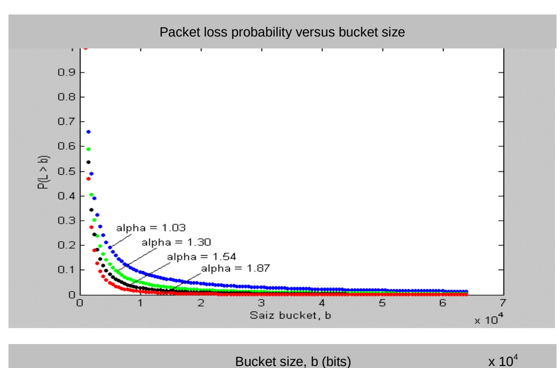
The TB scheme is parameterized with its basic parameters of ρ (token rate), b (bucket size), p (peak rate), m (minimum controlled unit), and M (maximum packet size) [18]. Typically, the released traffic A from a TB scheme for a time duration t is bounded by its token rate ρ and bucket size b. Mathematically, it is expressed as $A \le \rho t + b$. Hence, depending on the transmission time t, token rate ρ and bucket size b can be used to control the traffic burstiness. In implementing this, a procedure must be in place to make sure that token rate does not overflows the bucket capacity, i.e. $\rho \le b$.

However, as can be observed, TB contains no parameter that can be used to describe the link quality. Therefore, TC is proposed to work with TB for the reason that the basic parameters of TB are not sufficient to completely describe the application requirements into a traffic-descriptor. As mentioned earlier, this traffic-descriptor is an agent to tell the Resource Manager for the requested resources. When adaptation on QoS is required, TC will send feedback to TB.

Based on the system model and given a Pareto distribution (α, k), the probability that a packet will have a size of length $L > b$, i.e. the probability that a packet will be discarded is [17]

$$p = P(L > b) = \int_b^\infty f(x)dx = \int_b^\infty \frac{\alpha . k^\alpha}{x^{\alpha+1}} dx = (k/b)^\alpha \quad (6)$$

where $f(x)$ is the pdf for packet size L, α is the shape parameter (α > 1), and k is the scale parameter that limits the b value. This equation can also be interpreted as packet lost probability. It is observed that p is a function of b. When p versus b is plotted, a hyperbolic graph with slow decaying rate is obtained as shown in Figure 3. One can notice that as α increases, the tail of the hyperbolic graph decaying at much slower rate, and thus the burstier the traffic stream.



On the other hand, the transmission delay experienced by a packet from this sender/router node on any of its possible outgoing links can be expressed as [20]

$$d = b / r \tag{7}$$

where r is the bit rate of the available outgoing links.

Since each packet type of DMx or DHx is having its own maximum bit rate (carrying capacity) as specified in its specification [10], then r is assumed to have the bit rate of the transmitted packet. As can be seen, d is directly related to TB via b but indirectly related to TB via r, as r is not a basic TB parameter. In this case, r is obtained from TC. When d versus b is plotted, a straight line graph is obtained as depicted in Figure 4.

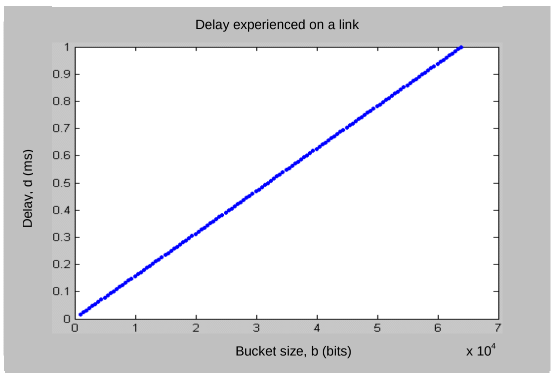


Figure 4. A straight line graph of delay on a link

Mathematics of algebra is used to derive the *traffic-descriptor* of (r, b). This is actually the intersection point between the graphs of hyperbolic and straight line, which is achieved by equating equation (6) to equation (7) as depicted in Figure 5. The (r, b) point represents an optimal application requirements for the resources.

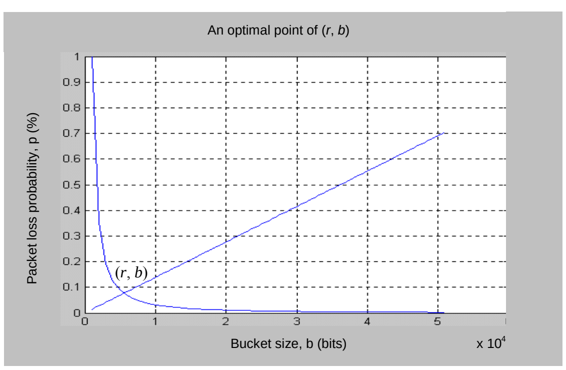


Figure 5. A traffic-descriptor of (r, b)

Given the bit rate r of the selected forwarding link, the required bucket size for a packet transmission can be computed from

$$b = (rk^{\alpha})^{1/(1+\alpha)} \tag{8}$$

By taking into account the bit rate of the link suitable for transmission of a specific packet type, the QoS routing decisions can now be expected to be more efficient and reliable. That is to say, the transmission of a packet over a link would be more efficient and reliable if the bit rate of the forwarding link can perfectly accommodate the required bit rate of the application.

However, in order to provide a much better level of efficiency and reliability for the QoS decisions, extended characteristics of the source traffic and the forwarding link may need to be considered when routing are to be made at a sender/router node. The packet's efficiency, as stated in [16] is expressed as $\varepsilon = \varphi \,/\, ((\xi + 1) \text{ x } \delta)$, where φ is maximum bit number for a packet type, $(\xi + 1)$ is the number of slot for a single packet inclusive it's acknowledgment slot, and δ is the length of a slot in bit. Based on this, the efficiency of each packet type is computed and tabulated as in Table 1.

Table 1. Packet efficiency

Packet type	Efficiency, ε
DH5	0.72
DM5	0.48
DH3	0.59
DM3	0.39
DH1	0.17
DM1	0.10

On the other hand, the quality of a forwarding link can be measured through *PER* value of the link, which is dependent on the packet type to be transmitted on that link. They are stated respectively as follows [16].

For DHx packet type:

$$PER = 1-(1-BER)^{s} \tag{9}$$

For DMx packet type:

$$PER=1-((1-BER)^{15}+15*BER*(1-BER)^{14})^{s/15} \tag{10}$$

where s is the maximum packet size (user payload) in bit unit and *BER* is the bit error rate of the forwarding link. In Bluetooth network, the *BER* value should not be greater than 10^{-3} for good signal reception [21].

From equation (8), r is a fix value for the bit rate of the link, which cannot be adjusted according to different packet types to be transmitted. However, work by [16] has identified different effective bit rates $R(X)$ for a forwarding link depending on the packet types to be carried on that link. Thus, by taking into account the packet efficiency and the link quality, the effective bit rate on a forwarding link can now be expressed as

$$R(X) = (1 - PER(X)) \times \varepsilon \times \psi \quad (11)$$

where ψ is the nominal bit rate provided by a Bluetooth network (1 Mbps). Substituting equation (8) by equation (11), the bucket size suitable for achieving QoS routing decision is

$$b = [(1 - PER(X)) \times \varepsilon \times \psi \times k^{\alpha}]^{1/(1+\alpha)} \quad (12)$$

From equation (11) and equation (12), a new *traffic-descriptor* of ($R(X)$, b) is now produced. This traffic-descriptor not only considers the properties of the source traffic (i.e. the self-similarity and the packet efficiency), but also the quality of the forwarding link. With this information, network resources are allocated and reserved to the requesting application based on realistic scenario of the network environment. In this way, efficient and reliable QoS routing decisions could be made at a sender/router node. Also, the traffic-descriptor contains only least number of parameters, but has the ability to describe the application requirements in a more accurate and deterministic manner. In this way, a parsimonious traffic-descriptor is developed. More importantly, the traffic-descriptor has a non-TB parameter, which is useful to represent other parameters that are not part of the basic TB parameters.

It is important to note that this QoS routing decision will move hop-by-hop from the source node to the next intermediary router nodes until the final destination node is reached. In this case, a complete route is made up of multiple links connecting a sender node to a receiver node in a topology of Bluetooth scatternet network.

3.2 The Source Traffic

There are three traffic types normally researchers used in the study of traffic engineering: on-line experimental traffic, generated traffic, or video traces traffic. Video traces are used in this work for the reason that they are readily available for on-line simulation runs, by which the frame sizes can be directly segmented into packet counts. Also, they have been identified to contain MPEG encoded data, which are bursty and proven to associate with self-similar property [7, 9]. The other traffic types require some forms of conversion before packet counts could be produced, which introduced transmission delays.

Therefore, the bursty source traffics are to be obtained from *Jurassic Park* and *Soccer* video traces. These traces can be downloaded for free from public domain URL of http://www-tkn.ee.tu-berlin.de/research/trace.trace.html. Each trace is represented by a set of frame numbers, and each frame has its frame size. Both traces have the same frame number of 89,998 but each frame has different byte length. Therefore, there is always a chance for the two traces to be different from each other, particularly with respect to the number of packets they can produce when the SAR segmentation scheme is applied on each frame of the trace file.

3.3 The Simulation

A simulation area of 100 m x 100 m is used to simulate the decision making process by a router node to select its forwarding link in a scatternet topology. This area size is to comply with the maximum of Class 1 power transmission radius of 100 m [10]. In the simulation area, nodes with other lower transmission radius of 10 m (Class 3) or 20 m (Class 2) can also be simulated. The number of nodes in the simulation area is set to any value from 100 to 200. This number has a significant impact on the chance of connectivity, i.e. the dense the node population, the higher the connectivity options for a router node. Figure 6 illustrates the simulation area, where the dots represent the mobile devices. As indicated in the figure, a route connecting a source node at one end and a destination node at the other end is made up of several links, hop by hop.

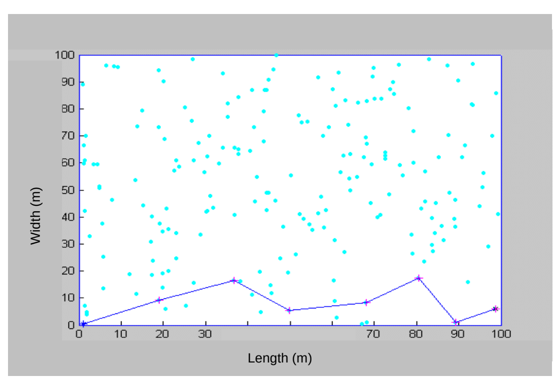


Figure 6. The simulation area

For simplicity, the source node is positioned at the bottom left of the area, while the destination node is positioned randomly. In this way, longest route could be developed connecting a sender node at the bottom left position and a destination node at the upper right position. According to [22] and several others works, it has been identified that a route may become inefficient in term of its throughput if the hop count traversed in a scatternet topology is greater than 6. Technically, this hop number can be controlled by using correct power class, by which it provides transmission radius.

A Matlab router simulated environment is developed to measure the two important characteristics of the bursty source traffic: the burstiness level α and the degree of self-similarity *H*. The relationship between them for Pareto distribution is $H = (3-\alpha)/2$. On the other hand, the link quality for the simulation can be measured via *BER* value. It is assumed that this *BER* value can be collected at the card level as described in [23].

As stated by [6, 24], α is an indicator of the burstiness level in a traffic stream. For the source traffic to have a heavy-tailed distribution, an interval of $0 < \alpha < 2$ must be obtained, where $\alpha \rightarrow 1$ indicates too bursty traffic stream. Subsequently, to measure the degree of self-similarity, an interval of $0.5 \leq H < 1$ is to be obtained. A high degree of self-similarity is indicated in the traffic stream when $H \rightarrow 1$.

As modeled in Figure 2, SAR segmentation protocol of *Best-Fit* [25] is used to segment the received L2CAP data stream from higher layer applications into smaller DHx or DMx packets. Once segmented, then these packets are submitted into the network through TB and TC schemes. This algorithm is chosen for the reason that it tends to produce more DHx packets than DMx packets, by which the DHx packet type could carry more payloads in a single transmission. The DMx packets can only carry fewer payloads, however. Therefore, DHx packets are the preferred choice for transmission in Bluetooth network. Figure 7 illustrates the *Best-Fit* SAR algorithm that is implemented at a sender/router node. The result of the segmentation is a total number of packets produced according to packet type used. Subsequently, *QQ-plot* method as described in [26] can be used to determine the slope α of the straight line graph produced. The different α values can then be computed from *Jurassic Park* and *Soccer* video traces to indicate the heavy-tailedness of the traffic stream.

```
begin
 if frame_size >= 339
  frame_size/339
  remainder_frame_size=mod(frame_size/339)
 else
  if 183 <= remainder_frame_size < 339
   remainder_frame_size/183
   remainder_frame_size=mod(frame_size/183)
  else
   if 27 <= remainder_frame_size < 183
    remainder_frame_size/27
    remainder_frame_size=mod(frame_size/27)
   else
    remainder_frame_size=mod(frame_size/27)
   end
  end
 end
end
```

Figure 7. The *Best-Fit* SAR algorithm

The purpose of this simulation is to develop a *traffic-descriptor* of (*R*(*X*), *b*). This information will be conveyed to Resource Manager for resource allocation and reservation. However, in accommodating the requirements but constrained by the limited resources, QoS adaptation may be required.

4. RESULTS AND ANALYSIS

Based on the system model described in Section 3.1, Table 2 provides the computation results for traffic-descriptor of (*R*(*X*), *b*) when DH5 packet was used in a transmission. The result was collected from an average reading computed for a number of hops in a complete route connecting a sender-receiver pair. The α value is calculated using *QQ-plot* method as mentioned in earlier section for every frame range.

Table 2. The (*R*(*X*), *b*) for DH5 packet

Frame range	α		(*R*(*X*), *b*)	
	Jurassic	Soccer	Jurassic	Soccer
5,000	0.910	0.911	719374, 30870	719379, 30887
10,000	0.918	0.918	718976, 30384	718981, 30395
15,000	0.926	0.927	718931, 30124	718928, 30134
20,000	0.937	0.935	719381, 29849	719389, 29850
25,000	0.952	0.953	718714, 29051	718720, 29048
30,000	0.967	0.968	719116, 28323	719121, 28332
35,000	0.983	0.983	719177, 27552	719170, 27565
40,000	0.994	0.994	719356, 27047	719358, 27053
45,000	1.001	1.002	718025, 26721	718029, 26717
50,000	1.008	1.009	719300, 26453	719296, 26459
55,000	1.012	1.012	719196, 26267	719200, 26273
60,000	1.019	1.018	715380, 25927	715384, 25930
65,000	1.024	1.025	718904, 25778	718900, 25781
70,000	1.028	1.029	714636, 25510	714643, 25507
75,000	1.032	1.031	718406, 25450	718410, 25459
80,000	1.034	1.035	719346, 25349	719349, 25354
85,000	1.037	1.037	715426, 25189	715433, 25196
89,998	1.038	1.039	719136, 25205	719138, 25200

Figure 8 shows the burstiness level of the traffic stream according to the bucket size used in that transmission. In general, both video traces of *Jurassic Park* and *Soccer* have produced the same graph pattern. Probably this has been contributed from roughly the same number of packet count produced from each segmented frame. Four observations could be made from the graph and the above table.

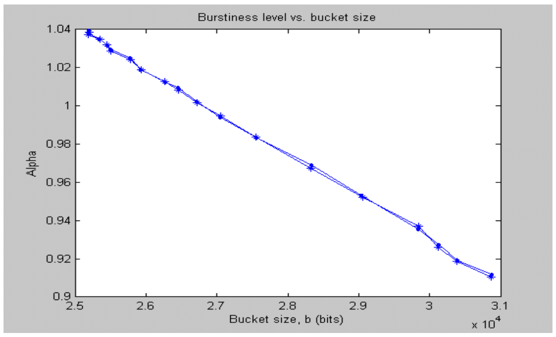


Figure 8. Burstiness level versus bucket size

First, traffic-descriptors of ($R(X)$, b) that described the characteristics of the source bursty traffic and the varying channel conditions have been successfully developed. This pair value should be able to provide sufficient information to the Resource Manager about the requirements of an application for the network resources that need to be allocated and reserved. Depending on the frame range and the number of packets produced after segmentation, the resulting ($R(X)$, b) may differ from each other. While the $R(X)$ values changed randomly and not following a certain order, the b values reduced linearly as α values go higher.

Second, the precision of the ($R(X)$, b) traffic-descriptor could be observed from the values of effective bit rate $R(X)$. The mean value for $R(X)$ is 718380 bps for both *Jurassic Park* and *Soccer*. When this value is compared against the largest allowable bit rate of 723200 bps for DH5 packet [10, 27], the mean value is clearly within an acceptable range. The difference between them is only 4820 bps, which is equivalent to 0.66%. In particular, after taking into account the link condition at the time when routing decision is to be made, the effective bit rate values are reflecting a set of realistic values suitable for practical implementation.

Third, there exist almost a linear relationship between the burstiness level α and the bucket size b. As the bucket size decreases, the burstiness level increases linearly, i.e. smaller bucket size triggers high variability in the traffic stream. From the graph, it can be seen that this is in conformance to the claim that as $\alpha \rightarrow 1$, the traffic stream is associated with a high degree of burstiness. Therefore, it can be anticipated that at the time when small bucket size is used and burstiness level is high, non-deterministic performance of the traffic-descriptor for QoS routing decisions at a router node may have occurred.

Forth, the linear relation can also be interpreted as an opportunity to control the burstiness level in a traffic stream, i.e. bucket size can be used to control the burst of the traffic stream. With smaller bucket size used would result in a high degree of burstiness (i.e. the more variability) in the traffic stream. This finding is in line with the theory we have developed in Section 3.1. Therefore, to achieve QoS routing decisions, bigger bucket size should be used. However, there must be a limit on the bucket size, since too big bucket size may lead to processing and transmission delays. Apart from the condition that $\rho \leq b$ should be used to control the bucket size, equation (7) may also be used to determine the maximum limit of the bucket size.

5. CONCLUSION

Our contribution is in the development of a parsimonious traffic-descriptor for Bluetooth ad hoc network in its topology of scatternet. In particular, the developed traffic-descriptor has parsimoniously described the application requirements to the Resource Manager for the required resources, by which the QoS routing decisions are made to be more efficient and reliable. The traffic-descriptor has only two parameters (very least number of parameters) but has successfully characterized the source traffic and the link quality into a traffic-descriptor. However, the developed traffic-descriptor is application-dependent, where it can only be used within the environment of Bluetooth network setting. This is because the mathematical model of the traffic-descriptor was designed to capture and to use very specific parameters of the Bluetooth network. Hence, more generic traffic-descriptor is needed to characterize other network settings.

The ($R(X)$, b) traffic-descriptor is observed to contain $R(X)$, which is a non-TB parameter. Therefore, we have successfully embedding a non-TB parameter into the traffic-descriptor to describe the application requirements, and not limited to only the standard TB parameters. Parameter $R(X)$ describes the packet efficiency and the link quality used, thus leading to accurate allocation and reservation for the required but limited resources. This would definitely lead to better QoS routing decisions at a router node.

It was found that the traffic-descriptor has precisely described the required *R*(*X*) to only 0.66% difference. Therefore, the developed mathematical model is assumed to work correctly and represents the system accordingly. The final result shall be exhibited through the optimal usage of the network resources. This is critically needed as to achieve efficient and reliable routing decision-making processes at a sender node, since Bluetooth network is having only a handful of resources.

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