The Dimensioning of Non-Token-Bucket Parameters for Efficient and Reliable QoS Routing Decisions in Bluetooth Ad Hoc Network

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Abstract

Bursty traffics are known to associate with self-similar property. It has a direct impact on network performance. Channel quality may also affect the performance, particularly when QoS routing decisions are to be made at a router node. Possibly, if parameters of the source traffic and the forwarding link can be precisely dimensioned for resource reservation, a better level of QoS guarantee can then be granted to user applications. The development of a traffic-descriptor thus far however, had only considered the Token-Bucket parameters, while the use of non-Token-Bucket parameters, which may contribute significantly to QoS achievement have been omitted. Hence, if resource-limited Bluetooth network is to be used, a parsimonious traffic-descriptor that also contained non-Token-Bucket parameters must be developed for efficient and reliable routing decisions. A Matlab simulated router node was used to measure the performance of the proposed traffic-descriptor. It was found that a parsimonious traffic-descriptor could be generated with a promising performance.

1. Introduction

For certain applications, Bluetooth ad hoc network may be well suited to be deployed replacing the other wireless technologies. However, Bluetooth network is well known for its limited resources [1]. Therefore, providing Quality of Service (QoS) in Bluetooth network has become a major issue, particularly with respect to the level of service guarantees that it can offer to the requesting applications. One of such applications in ad hoc networking is routing function at a router node, which the service guarantee can be measured from its routing efficiency and reliability.

Figure 1 depicts a router node i, at which decision is to be made to select a forwarding link for the received packets from the three available links, based on certain criteria (e.g. the bit rate of the link). A mapping between the available bit rate of the link and the requested bit rate of an application is performed. The selected forwarding link not only has to satisfy the demand of the bit rate but also to provide certain degree of service guarantee. However, in many nowadays complex and sophisticated application scenarios, there are multiple QoS demands that need to be satisfied. For this reason, the selected forwarding link may be able to provide only an optimal solution. A route is a set of links. Therefore, a set of routing decisions are to be made at each router node connecting a sender and a receiver in a network topology. The final result shall be exhibited through an optimal usage of the limited network resources.

Figure 1. Routing decision at a router node

Apart from the criteria of the forwarding link, the characteristics of the source traffic may also affect the efficiency and reliability of a routing function. Generally, traffic of real-time and interactive applications from web browsing, audio/video conferencing, video-on-demand, forecasting, sensoring, on-line transactions, and multiparty games are bursty in nature. In its simplest form, burst is defined by [2] as the ratio between peak and mean bit rate. In many
cases, burst can be triggered from rare-event. For example, large size file transfer when compared to the transfer of average file size. As determined by [3], bursty traffic is associated to self-similar property, by which its performance measure is difficult to obtain. This leads to a situation in which QoS is hard to achieve because the traffic’s characteristic cannot be precisely described to Resource Manager for reservation and allocation when routing decisions are involved. As a result, efficiency and reliability in routing decision by a router node may not be able to be obtained. Simply, bursty source traffic has a direct impact on network performance.

Therefore, if the characteristics of the source traffic are to be described, a traffic characterization process is required, and as a result a traffic-descriptor will be produced. That is, traffic-description of the incoming traffic is used to provide QoS in such a way that resources are reserved and allocated according to the characteristics of the traffic pattern. Some other parameters of the network may also be considered.

However, the problem lies in the formulation of a mathematical model that could parsimoniously incorporate only least possible parameters but well describing the application’s QoS requirements into an appropriate traffic-descriptor. Specifically, how the non-Token-Bucket parameters, which may contribute significantly to the efficiency and reliability of a routing function can be embedded into a traffic-descriptor, and not limited to only the Token-Bucket parameters. This is critical for Bluetooth network for two very basic reasons. First, most of the time, only a single link is provided between any two communicating devices, thus no option available to select any other efficient and reliable links. The only-one-link situation is always created in Bluetooth network because of the master-driven communication approach, whereby a slave node cannot directly communicate with another slave node, except through a master node. Second, Bluetooth is a resource-limited network provided with low-cost, low-power, and short-distance communication capabilities. Therefore, Bluetooth has many constraints with respect to its ability to fulfill the ever-increasing demands for the QoS guarantees.

Hence, the objective of this research paper is to develop a parsimonious traffic-descriptor that could incorporate the non-Token-Bucket parameters so that efficient and reliable routing decisions could be made at a router node. To achieve this, the dimensioning of the non-Token-Bucket parameters together with the basic Token-Bucket parameters is necessary.

For the purpose of producing a traffic-descriptor, a mathematical model that measures the burstiness level $\alpha$ and the degree of self-similarity $H$ in a traffic stream, as well as the channel quality (via BER) must be developed. Using this deterministic information, the QoS provisioning shall be more guaranteed. However, the exact resource reservation and allocation procedures are not within the scope of this paper; it shall be given to Resource Manager. Thus, this work is limited to only producing traffic-descriptor for Resource Manager to use.

The rest of the paper is organized as follows. Section 2 discusses the self-similar property and the dimensioning of Token-Bucket parameters. Section 3 explains the methodology to derive a traffic-descriptor. Results and analysis on the performance of a traffic-descriptor at a router node are presented in Section 4. Finally, conclusion is made in Section 5.

2. Related works

2.1 Self-similar traffic

It has been a long belief that network traffic is following Poisson distribution, but in actual fact it was only applied to speech data of the telephony system. Leland and his research team have provided evidence that the inter-arrival times for bursty traffics in local area network (LAN) is following heavy-tailed distribution of power law [4]. Their study on Ethernet LAN traffics from 1989 to 1992 has established that fractal (self-similar) property in a traffic stream could not any longer be captured by conventional traffic model. Supported by [5], it was confirmed that the packets’ inter-arrival times have deviated away from exponential distribution. Additionally, a work by [6] has determined that variable bit rate of MPEG video traffic is associated to self-similarity, which is common property for bursty traffics.

On an ad hoc network type, Bluetooth implements Segmentation and Reassembly (SAR) protocol at L2CAP layer, by which long message blocks received from upper layers are segmented into smaller packets types of DMx or DHx (M – Medium, H – High, x = 1, 2, or 3 slots). 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. To describe heavy-tailed distribution and self-similar property, second order statistics is required.

Heavy-tailed distribution is defined as follows [7]. Let $X$ be a random variable with cumulative distribution function (cdf) of $F(x) = P(X \leq x)$ and complementary cumulative distribution function (ccdf)
of \( F(x) = 1 - F(x) = P(X > x) \). A distribution \( F(x) \) is said to be heavy-tailed if:

\[
F(x) = P(X > x) \sim cx^{-\alpha} \quad (1)
\]

when \( x \to \infty \) for positive \( c \) value and \( 0 < \alpha < 2 \). In other words, a distribution is heavy-tailed if the 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 a power law distribution. One of the simplest heavy-tailed distribution is Pareto distribution with probability distribution function (pdf) of

\[
f(x) = \alpha k^\alpha x^{-(\alpha + 1)}, \quad \text{where} \quad \alpha > 0, \quad 0 < k \leq x.
\]

Accordingly, the distribution is having cdf of

\[
F(x) = P(X \leq x) = 1 - (k/x)^\alpha
\]

and ccdf of

\[
\bar{F}(x) = P(X > x) = (k/x)^\alpha \quad (3)
\]

where \( \alpha \) is a shape parameter and \( k \) is a scale parameter.

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

One important property of a heavy-tailed distribution is that it is self-similar, as have been proved by [4] and supported by [8]. Additionally, as claimed by [9], superimposition of several independent of ON/OFF heavy-tailed traffic sources is just enough to produce a self-similar traffic stream. Self-similarity is defined as follows [10]. Let \( \lambda(t) \) be a wide-sense stationary time series with mean \( \mu \), variance \( \sigma^2 \), and autocorrelation function \( \rho(\tau) \). Let \( \Lambda^\alpha(t) \) be a newly derived time series from \( \Lambda(t) \) by averaging a number of \( m \) non-overlapping block sizes. Its aggregated series is:

\[
\Lambda^\alpha(t) = (m^{-1})(X_{m-m+1} + X_{m-m+2} + \ldots + X_m) \quad (4)
\]

and \( \rho^\alpha(\tau) \) is its autocorrelation function. Process \( \Lambda(t) \) is said to be self-similar if:

\[
\rho^\alpha(\tau) = \rho(\tau) \quad \text{for} \quad m = 1, 2, 3, \ldots
\]

A work by [3] has provided evidence that self-similar property has a direct impact on network performance. Also, as identified by [4], 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 level of burstiness \( \alpha \) and the degree of self-similarity \( H \) in the source traffic stream. The relationship between \( \alpha \) and \( H \) for Pareto distribution has been derived by [4] and is expressed as \( H = (3-\alpha)/2 \). Combined with some other detailed characteristics of the traffic stream and/or system, such as packets’ efficiency and channel quality, the QoS requirements of an application can be described to Resource Manager in a much more precise manner. It is stated as a traffic-descriptor. In this way, much better resource reservations could be made and deterministic network performance could be obtained. Then, QoS can be granted to user applications with higher degree of confidence.

### 2.2 Token-Bucket scheme

There have been many works in the literature on the use of Token-Bucket (TB) scheme for traffic regulation by using only its own basic parameters. Work by [11], however, improvised the TB by including a fuzzy logic component, resulting in a fuzzy logic TB predictor that has the capability to adapt its token rate based on actual traffic requirement. In this way, the actual bandwidth requirement can be gauged and feedback is relayed to Admission Control mechanism. In order to characterize the bursty input traffic, TB scheme may be used in a 2-in-1 combined function [12]. The first function is to regulate the arriving bursts to a more controllable and deterministic form of traffic flow. The second function is to characterize the incoming self-similar traffic so that a traffic-descriptor is produced.

Typically, a traffic-descriptor is expressed as \( (\rho, b) \), where \( \rho \) is the token rate and \( b \) is the bucket size, and both are the basic TB parameters. Papers by [13] and [14] elaborate the production of a traffic-descriptor using the TB scheme. However, work by [15] has suggested a traffic-descriptor of the form \( (\rho, unlimited) \), by which the bucket size \( b \) can be as large as possible. However, as confirmed by queuing systems, the larger the bucket size the longer the processing delay experienced by the packets in the queue. This claim is supported by a scheduling work of [16]. Study by [12] could be the best piece of work that has takes into account the self-similar property of the source traffic for QoS routing decisions at a router node, by which the other previous works did not.

However, the TB scheme alone may not be able to completely describe the source traffic and the network characteristics. Therefore, other components may be required to work with TB, which these components will provide the necessary additional parameters. The expected result shall be of a more accurate allocation of
network resources to the requesting applications for each of the router’s forwarding link.

However, the critical issue for QoS provisioning in high-speed network is to find an appropriate probabilistic model for the source traffic, in particular if stochastic approach is used [23]. As determined by [13], the production of a traffic-descriptor is application-dependent and case-sensitive. Furthermore, [14] stated that until today, a standard procedure to produce a traffic-descriptor is still none existence. Therefore, a parsimonious traffic-descriptor for a Bluetooth ad hoc network is needed for efficient and reliable routing decisions. Parsimonious is referred to as having only least possible parameters but well describing the system in question. This is because the more parameters to handle, the more resources are required, which may not lead to efficiency and reliability in routing decisions. Therefore, parsimonious is very much needed in Bluetooth network since it has only limited links and resources to be offered.

3. Methodology

3.1 The system model

Figure 2 represents a system model of a router node, at which routing decisions are to be simulated. A router node accepts an input traffic and subsequently forwards the received traffic onto an outgoing link based on certain decision criteria. The routing decisions are to be made by a combined function of Token Bucket (TB) and Transmission Controller (TC).

![Figure 2. The system model of a router node](image)

At the input point before submission to TB, the SAR protocol accepts frames from upper layer and segments them into smaller packets of DHx or DMx. The types of packet produced will be determined by the SAR algorithm, which in this work Best-Fit algorithm was chosen. These packets are then put in a buffer queue with length \( L \), where the queue management is a simple FIFO. A packet of size \( L \) can only proceed with transmission when there is a bucket size \( b \) to carry the packet, i.e. \( L \leq b \). On the other hand, if \( L > b \), the bucket size cannot accommodate the packet size, thus discarded from the system. When this happened, there exists packet loss probability. In a system with bursty traffic source, this loss probability is allowed to occur.

TB is used together with TC to produce a traffic-descriptor, which then will be used for resources reservation for QoS routing decisions. Simply, a traffic-descriptor describes the QoS requirement of the input traffic. The main function of a TB is to make routing decisions. However, TB is only parameterized with its basic parameters of \( p \) (token rate), \( b \) (bucket size), \( m \) (minimum controlled unit), and \( M \) (maximum packet size) [14]. Therefore, in this work, TC is proposed to work with TB for the reason that the basic parameters of TB are not sufficient to completely describe the traffic QoS requirements if other decision criteria are to be considered in the decision model.

The fundamental function of a TC is to control the transmission: if the QoS requirement of the traffic is fulfilled against the available resources, forwarding of packet data over a link is allowed; else select the other links (if available). If other links are not found, just use the only available link, probably with QoS adaptation. When adaptation is required, for example when the available resources are not sufficient to accommodate the traffic requirement but to achieve certain level of QoS provisioning, TC will send feedback to TB. TB will then make the necessary adjustment.

3.2 The mathematical model

Based on the system model and the requirement to handle self-similar traffic with Pareto distribution \( (\alpha, k) \), the probability that a packet will have a size of length \( L > b \) is [13]:

\[
p = P(L > b) = \int_{b}^{\infty} \frac{\alpha k^\alpha}{x^{\alpha+1}} dx = (k / b)^\alpha
\]

where \( f(x) \) is the pdf for packet size \( L \), \( \alpha \) is the shape parameter \( (\alpha > 1) \), and \( k \) is the scale parameter that limits the \( b \) value. This equation can also be interpreted as packet lost probability, i.e. the probability a packet will be discarded. It is observed that \( p \) is a function of \( b \). When a graph of \( p \) versus \( b \) is plotted, a hyperbolic graph with slow decaying rate is obtained.

On the other hand, transmission delay experienced by a packet from this router node to the next node over a selected link can be expressed as [16]:

\[
d = b / r
\]
where $r$ is the bit rate of the forwarding link. Since, each packet type of DHx or DMx is having its own maximum bit rate, 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 $r$, since $r$ is not a basic TB parameter. In this case, $r$ is to be obtained from the TC, which is a non-TB parameter. When a graph of $d$ versus $b$ is plotted, a straight-line graph is obtained.

The mathematics of algebra is used to derive the ($r$, $b$) pair, which is known as a traffic-descriptor. This pair value is the intersection point between the graphs of hyperbolic and straight line, as a result of equating Equation (6) to Equation (7). Given $r$, the required bucket size can be computed as:

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

(8)

Therefore, by taking into account the bit rate of the forwarding link suitable for transmission of a specific packet type, the QoS routing decisions can now be expected to be more efficient and reliable.

However, in order to provide a much better level of QoS routing decisions at a router node, further improvement could be made on the above mathematical model. In this work, specific characteristics of the source traffic and the quality of the forwarding link are further investigated. By doing so, improved efficiency and reliability for the QoS routing decisions can be expected.

One of the interesting characteristics from the source traffic is the efficiency of Bluetooth packet. The packet’s efficiency, as stated in [17], is expressed as $\varepsilon = \phi / ((\xi + 1) \times \delta)$, where $\phi$ 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 $\delta$ is the length of a slot in bit. The efficiency of each packet type has been computed and tabulated in Table 1.

### Table 1. Bluetooth packet efficiency

| Packet type | Efficiency, $\varepsilon$ |
|-------------|--------------------------|
| DH5         | 0.72                     |
| DM5         | 0.48                     |
| DH3         | 0.59                     |
| DM3         | 0.39                     |
| DH1         | 0.17                     |
| DM1         | 0.10                     |

Further improvement on routing efficiency and reliability can also be achieved from the quality of the outgoing link. Typically, the quality of a forwarding link can be measured from its PER value, which is determined by the packet type forwarded on that link. They are stated respectively as follows [18]:

$$PER = 1 - (1 - BER)^{\delta}$$  

for DHx (9)

$$PER = 1 - ((1 - BER)^{15} + 15 \times BER \times (1 - BER))^{1/15} / 15$$  

for DMx (10)

where $s$ is the maximum packet size (user payload) in bit unit and $BER$ is the bit error rate of the link. It is assumed that a router node has the ability to measure the $BER$ of each of its outgoing links. In Bluetooth network, the $BER$ value shall not be greater than $10^{-3}$ for good signal reception.

Taking into account the packet efficiency and the channel quality, the effective bit rate $R(X)$ for DHx or DMx packets can now be expressed as [17]:

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

(11)

where $\psi$ is the nominal bit rate provided by a Bluetooth network, which is 1 Mbps. Substituting Equation (8) by Equation (11), the bucket size is obtained as:

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

(12)

From Equation (11) and Equation (12), a new traffic-descriptor of the form of ($R(X), b$) is now produced. This traffic-descriptor not only takes into account the properties of the source traffic (i.e. the self-similarity and packet efficiency), but also the quality of the forwarding link. With these deterministic set of information, network resources are reserved and allocated to the requesting application based on true scenario of the network environment. In this way, much better efficiency and reliability for the QoS routing decisions could be made at each of the router node.

### 3.3 The source traffic

There are three types of traffics normally used by researchers in the study of traffic engineering: on-line experimental traffic, generated traffic, or video traces. In this work, video traces are chosen for the reason that they are readily available for on-line simulation, 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 [6]. The other traffic types, however, require some forms of conversion before packet counts could be produced, which may introduce transmission delays.

The bursty source traffics are to be generated from Jurassic Park and Soccer video traces. They can be obtained from public domain of [http://www-tkn.ee.tu-berlin.de/research/trace.trace.html](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, particularly with respect to the number of packets they produced when the SAR segmentation scheme is applied on each of the frame.

3.4 The simulation

A simulated router node has been developed using Matlab to measure the two important characteristics of a bursty traffic: the burstiness level $\alpha$ and the degree of self-similarity $H$. The relationship between them for Pareto distribution is $H = (3-\alpha)/2$. As stated by [19], $\alpha$ is an indicator of the burstiness level in a traffic stream. For the source traffic to have a heavy-tailed distribution, an interval of $1 < \alpha < 2$ must be obtained, where $\alpha \to 1$ indicates too bursty traffic. On the other hand, to measure the degree of self-similarity, an interval of $0.5 \leq H < 1$ is to be obtained. $H \to 1$ indicates a high degree of self-similarity.

As modeled in Figure 2, SAR protocol of Best-Fit algorithm [20] is used to segment the received data stream into smaller DHx or DMx packets. Figure 3 illustrates the segmentation scheme implemented at a router node, which produced a total number of packets according to packet types.

```
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
```

**Figure 3. The SAR Best-Fit Algorithm**

4. Results and analysis

Based on the models described in Section 3.1 and Section 3.2, Table 2 shows the computation results for the pair of $(R(X), b)$ when DH5 packet is used for routing decisions at a router node. The $\alpha$ value is calculated using $H = (3-\alpha)/2$, by which $H$ can be obtained from the QQ-plot method [21] for every frame range of Jurassic Park and Soccer video traces. Finally, $(R(X), b)$ is obtained.

| Frame range | $\alpha$ | Jurassic | Soccer | Jurassic | Soccer |
|-------------|---------|----------|--------|----------|--------|
| 5,000       | 0.910   | 719374   | 30870  | 719379   | 30887  |
| 10,000      | 0.918   | 718976   | 30384  | 718981   | 30395  |
| 15,000      | 0.926   | 718931   | 30124  | 718928   | 30134  |
| 20,000      | 0.937   | 719381   | 29849  | 719389   | 29850  |
| 25,000      | 0.952   | 718714   | 29051  | 718720   | 29048  |
| 30,000      | 0.967   | 719116   | 28323  | 719121   | 28332  |
| 35,000      | 0.983   | 719177   | 27552  | 719170   | 27565  |
| 40,000      | 0.994   | 719356   | 27047  | 719358   | 27053  |
| 45,000      | 1.001   | 718025   | 26722  | 718029   | 26717  |
| 50,000      | 1.008   | 719300   | 26453  | 719296   | 26459  |
| 55,000      | 1.012   | 719196   | 26277  | 719200   | 26273  |
| 60,000      | 1.019   | 715380   | 25927  | 715384   | 25930  |
| 65,000      | 1.024   | 718904   | 25778  | 718900   | 25781  |
| 70,000      | 1.028   | 714636   | 25510  | 714643   | 25507  |
| 75,000      | 1.032   | 718406   | 25450  | 718410   | 25459  |
| 80,000      | 1.034   | 719346   | 25349  | 719349   | 25354  |
| 85,000      | 1.037   | 715426   | 25189  | 715433   | 25196  |
| 89,998      | 1.038   | 719136   | 25205  | 719138   | 25200  |

Three observations could be made from this table. First, traffic-descriptors of $(R(X), b)$ for Jurassic Park and Soccer have been produced. This pair of values provides the requesting application with information, which can be conveyed to the Resource Manager for request, allocation, and reservation of resources. Depending on the frame range and the number of packets they produced after segmentation, the resulting values of $(R(X), b)$ may differ from each other. While the $R(X)$ values have changed randomly and not following a certain order, the $b$ values reduced linearly as $\alpha$ values go higher. In general, both video traces have produced the same graph pattern as illustrated in Figure 4.

**Figure 4. Burstiness level $\alpha$ vs bucket size $b$**
5. Conclusion and future work

A traffic-descriptor \((r, b)\) of which contained non-Token-Bucket parameters has been successfully developed. In particular, the developed traffic-descriptor has parsimoniously described the application requirement to the Resource Manager for the required resources. The model has been parameterized by only least number of parameters, but it has the capability to describe very well the traffic of its transmission delay from the queue. Therefore, \(\alpha \rightarrow 2\) (or equivalently \(H \rightarrow 0.5\)) is very much needed. In this way, traffic with lower burst level could be produced, by which the performance of a QoS routing control scheme could be more effective and reliable. This is critically needed when limited link and resources of Bluetooth network is used, but to provide a level of service guarantee to the requesting applications.

The QoS routing decisions at a router node are then made to be more efficient and reliable, but this is only applicable to Bluetooth setting. This is because the traffic-descriptor has characterized the source traffic and the channel quality by mean of a mathematical model that is dependent on Bluetooth network setting.

In the case of DH5 packet transmission, it was found that the traffic-descriptor has precisely described the required \(R(X)\) to only 0.66% difference from its maximum bit rate, whilst QoS guarantee is granted to user application when routing decision is made at a router node. Therefore, the developed mathematical model is assumed to represent the system correctly and to work 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, since Bluetooth network is having only a handful of resources.

Future work is to develop a general-purpose traffic-descriptor, which can be used to dimension any other non-Token-Bucket parameters for use in any wireless network settings.

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7. References

[1] J. Haartsen, W. Allen, J. Inouye, O.J. Joeressen, and M. Naghshineh, “Bluetooth: vision, goals and architecture”, ACM Mobile Computing and Communications Review, Vol. 1, No. 2, 1998, pp. 1-8.
[2] R. Handle, M. Anber, and S. Schroder, ATM Networks Concepts, Protocols and Applications, Addison-Wesley, New York, 1996.
[3] K. Park, G. Kim, and M. Crovella, “On the relationship between file sizes, transport protocols, and self-similar network traffic”, Proc. IEEE International Conference Network Protocols, 1996, pp. 171-180.
[4] W.E. Leland, M.S. Taquu, W. Willinger, and D.V. Wilson, “On the self-similar nature of Ethernet traffic (extended version)”, IEEE/ACM Transactions on Networking, Vol. 2, No. 1, 1994, pp. 1-15.
[5] V. Paxson, “Empirically derived analytic models of wide area TCP connections”, IEEE/ACM Transactions on Networking, Vol. 2, No. 4, 1994, pp. 316-336.
[6] J. Beran, Statistics for Long-Memory Processes, Chapman and Hall/CRC, 1st edition, New York, 1994.
[7] M.E. Crovella, and L. Lipsky, “Long-lasting transient conditions in simulations with heavy-tailed workloads”, Proc. Winter Simulation Conference, 1997, pp. 1005-1012.
[8] M.E. Crovella, and A. Bestavros, “Self-similarity in world wide web traffic: evidence and possible causes”, IEEE/ACM Transactions on Networking, Vol. 5, No. 6, 1999, pp. 835-846.
[9] M. Taquu, W. Willinger, and R. Sherman, “Proof of a fundamental result in self-similar traffic modeling”,
[10] S. Fernandes, C. Kamienski, and D. Sadok, “Accurate and fast replication on the generation of fractal network traffic using alternative probability models”, Proc. SPIE 5244, 2003, pp. 154-163.

[11] M.D. Norashidah, F. Norsheila, “Fuzzy logic Token Bucket bandwidth predictor for assured forwarding traffic in a DiffServ-aware MPLS Internet”, Proc. Asia International Conference on Modelling & Simulation (AMS’07), 2007.

[12] G. Procissi, M. Gerla, J. Kim, S.S. Lee, and M.Y. Sanadidi, “On long range dependence and Token Buckets”, Proc. SPECTS’01, 2001.

[13] F.Y. Li, “Local and global QoS-aware Token Bucket parameters determination for traffic conditioning in 3rd generation wireless networks”, Proc. European Wireless’02, 2002, pp. 362-368.

[14] J. Glasmann, M. Czermin, and A. Riedl, “Estimation of Token Bucket parameters for videoconferencing systems in corporate networks”, Proc. International Conference on Software, Telecommunications and Computer Networks, 2000.

[15] X. Yang, “Designing traffic profiles for bursty Internet traffic”, Proc. IEEE Global Internet, 2000, pp. 2149-2154.

[16] R.G. Garroppo, S. Giordano, S. Niccolini, and F. Russo, “A simulation analysis of aggregation strategies in WF²Q⁺ schedulers network”, IP Telephony ’01, 2001.

[17] J. Kim, Y. Lim, Y. Kim, and J.S. Ma, “An adaptive segmentation scheme for the Bluetooth-based wireless channel”, Proc. IEEE IC3N ’01, 2001, pp. 440-445.

[18] L.J. Chen, R. Kapoor, M.Y. Sanadidi, and M. Gerla, “Enhancing Bluetooth TCP throughput via link layer packet adaptation”, Proc. IEEE International Conference on Communications’04, 2004.

[19] Z. Hadzi-Velkov, and L. Garrilovska, “Performance of the IEEE802.11 wireless LANs and influence of hidden terminals”, Telsiks ’99, 1999, pp. 102-105.

[20] A. Das, A. Ghose, A. Razdan, H. Saran, and R. Shorey, “Enhancing performance of asynchronous data traffic over the Bluetooth wireless ad hoc network”, Proc. 20th Annual Joint Conference of IEEE Computer & Communications Society (INFOCOM 2001), 2001, pp. 591-600.

[21] T.D. Dinh, S. Molnar, and A. Vidacs, “Investigation of fractal properties in data traffic”, Journal of Communications, Vol. XLIX, 1998, pp. 12-18.

[22] Bluetooth specification v1.0B, Bluetooth SIG, 1999. Available at: http://www.bluetooth.com.

[23] S. Valaee, and J-C. Gregoire, “An estimator of regulator parameters in a stochastic setting”, IEEE/ACM Transaction on Networking, Vol. 13, No. 6, 2005, pp. 1376-1389.