# Increasing Connection Lifetimes through Dynamic Distribution of Budgeted Power

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***Abstract*—We present a new dynamic scheme which continuously redistributes a fixed power budget among mobile wireless nodes participating in a multi-hop wireless connection, with the objective of maximizing the expected lifetime of the connection. Our experimental simulations indicate that the proposed power budget distribution scheme yields a significant increase in connection lifetime. We quantify the sensitivity of the performance gains to various system parameters, including connection size, node density, power budget size, and mean node velocities. We then compare the efficacy of our scheme with two schemes: one that simply distributes the power budget uniformly, and one that distributes the power budget dynamically with the objective of minimizing end-to-end bit error rate (BER). In comparing the relative performance of the three schemes we obtain a qualitative assessment of the inherent oppositions and tradeoffs between the objectives of BER minimization and lifetime maximization.**

## I. Introduction

Historically [1] reconciling the gap between power consumption and supply involved solving the following issues: (i) improving the power *efficiency* in the system; and (ii) preventing the system deconstruction due to un*fair* power usage. In their earlier work [2], [3] the authors proposed addressing these concerns by normalizing the measurement of relative "efficiency" and "fairness" using a model in which every connection is assigned a fixed power utilization budget. This assigned budget reflects the connection's priority, or equivalently, the benefit that the system derives in maintaining the connection. In consumer MANETS, for example, this benefit might be based on financial incentives provided by a paying satisfied customer, while in military MANETs it could reflect the extent to which the connection is essential to achieving a positive outcome for some coordinated mission objective. In [4], the authors considered the opportunities afforded by such a model vis-a-vis minimizing connection bit error rate (BER), and presented a distributed scheme which minimized a connection's end to end BER by continuously reapportioning its power budget among its constituent (static) nodes.

This work diverges and extends the earlier investigations of the authors [4] in two very significant ways: First, this paper considers *mobile* nodes instead of merely considering static snapshots of a dynamic network; secondly, our objective here is to leverage the ability to dynamically distribute a connection's power budget towards *maximizing expected connection lifetime*, rather than towards minimizing connection BER. We will compare our proposed lifetime-maximizing scheme with the connection lifetimes enjoyed by the BER-minimizing power distribution scheme of [4], and in doing so obtain a sense of the extent to which the two objectives are in opposition.

## II. Related Work

Efficient power management for MANETs has been investigated in prior research at several protocol layers (see e.g. [1]). As an objective, lifetime maximization has been interpreted in one of two ways: network lifetime maximization, and connection lifetime maximization.

**Network Lifetime**. The lifetime of a network is most frequently defined as the time interval for which the network is a connected graph. Broadly speaking, the network may partition (becoming disconnected) when one of two events occurs: (i) the autonomous movement of a node causes some of its incident link(s) to fail due to a shortage of transmission power, or (ii) some node exhausts its energy supply sufficiently so that some of its incident links fail. Most prior research on network lifetime attempts to delay the onset of these two types of events—the most frequent emphasis being on event type (ii), see e.g. [5], [6]—by extending the network routing protocol to make it energy-aware and using a route selection strategy that facilitates optimization with respect to the network's lifetime.

**Connection Lifetime**. Somewhat analogously, a connection's lifetime is typically taken to be the time interval during which all of the connection's constituent links are operational. A link in a connection ceases to be operational when one of two events occurs: (a) the autonomous movement of one of the link's endpoints causes it to fall out of transmission range of the other endpoint, or (b) one of the two endpoints exhausts its energy supply, causing the other endpoint fall out of transmission range. Most prior research on connection lifetime attempts to delay the onset of these two types of events—the most frequent emphasis being on events of type (a), see e.g. [7], [8], [9], [10], [11]. The main approach has been (as was the case in research on network lifetime) to extend the network routing protocol by making it energy-aware, and then to make route selection sensitive to connection lifetime maximization. In [7], [8], [9], [10], for example, the authors proposed new routing protocol extensions based on finding the path which probably has longest lifetime among many possible the node density reaches $\delta = 0.4$ nodes per meter. Altering node density does not appear to separate *Sqr*'s advantage over *Uniform* from *Sqr*'s advantage over *minBER*.

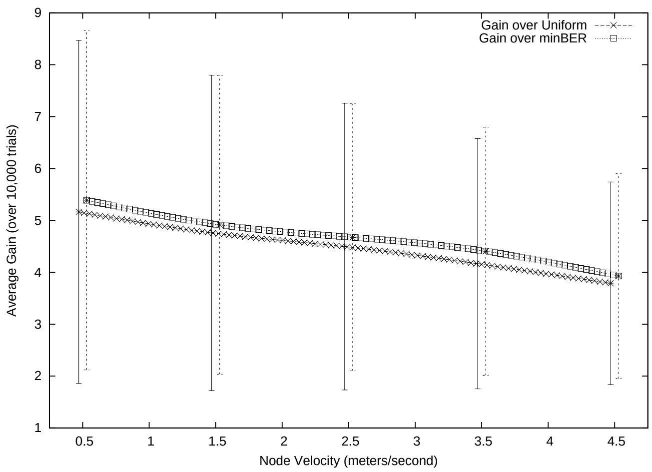


Fig. 5. The Influence of Node Velocity on Gain

**Varying the node velocity**. In the final set of experiments, we varied the mean node velocity from $0.5$ meters/sec to $4.5$ meters/sec, while keeping all other variables fixed: the power budget ($P$) was fixed at $5.0$W, and the initial mean node density was one node every $50$m. As can be seen in Figure 5, *Sqr* enjoys a significant factor of 5.2 gain in connection lifetime over both *Uniform* and *minBER*, although as node velocity increases, the gain is gradually reduced, becoming only a factor of 3.8 when the node velocity reaches $4.5$ meters/sec. Altering node velocity does not appear to separate *Sqr*'s advantage over *Uniform* from *Sqr*'s advantage over *minBER*.

## VIII. Conclusion

The proposed *Sqr* scheme is able to distribute a fixed power budget among the nodes of a connection, and yields significantly longer expected connection lifetimes relative to the uniform power budget distribution and the BER-minimizing power distribution schemes. The observed gains range from a factor of $3$ to a factor of $30$, depending on the particular values of system and environmental parameters. The expected gain is seen to be most sensitive to power budget and connection size, and relatively insensitive to initial node density and mean node velocity.

The objectives of BER minimization and lifetime maximization are most starkly in opposition in settings where the total power budget is low or, equivalently, where the size of the connection is large. It is in these settings that the distribution of power is most sensitive to the particular choice of objective, for in such settings, distributing power in a manner that achieves minimum end-to-end connection BER is very different from distributing power in a manner that seeks to maximize expected connection lifetime. The net impact of this tradeoff is that connections which are declared low priority (and hence assigned low power budgets) cannot expect to simultaneously optimize their power distributions with respect to both BER and expected lifetime, since the two criteria are seen to be in opposition. High-priority connections, on the other hand can "have their cake and eat it too", since with large power budgets, the relative advantage of *Sqr* over *minBER* (with respect to lifetime) is diminished.


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