I. INTRODUCTION

In recent years, there has been considerable interest in wireless mesh networks and their deployment in metropolitan areas, from both a commercial and a research perspective. Trials in several major cities in the US and worldwide have shown mesh networks to be a viable technology that can compete well with alternative “last-mile” connectivity solutions to the public. Correspondingly, most of the research on metropolitan-area wireless mesh networks (MAWMN) has focused on maximising the throughput that can be extracted from them, in the anticipation that their major use will be public, for purposes such as accessing the Internet or conducting voice calls. On the other hand, little attention has been directed to the aspects of reliability and latency, which are most important if MAWMN are to be considered for replacement of mission-critical infrastructure, such as traffic control system communications.

The Smart Transport and Roads Communications (STaR-Comm) project at National ICT Australia (NICTA), started in August 2005, sets out to develop protocols that enhance the reliability and reduce the latency of mesh networks, and thereby enable them to be used as the communications layer of traffic control systems. In this paper, we describe the testbed that has been built in the first stage of this project. Our initial testbed covers seven traffic lights in the suburban area of Sydney. These intersections are chosen because they represent a typical suburban area with lots of traffic, foliage, pedestrians and high-rise residential buildings. In addition, the inter-node distance (ranging from 200 to 500m) is representative of 90% of the distance between traffic controllers in the Sydney CBD (Central Business District) area. In the next phase, we plan to extend our testbed to 15-20 nodes. Our nodes have been custom-built to meet the need of our research.

The nodes are mounted on the traffic lights at a height of about 2-3m from the ground, and distributed along the streets in the form of rectangle covering an area of 500 × 1000 square metres at a distance of 200-500m apart. None of the nodes is in a clear line of sight of its neighboring nodes. One of the nodes is used as a gateway node and connected to Sydney University network. The hardware components used for the nodes of our initial testbed are all off-the-shelf products, as shown in Figure 2.

- **Wireless interfaces.** Each node has two wireless interfaces to connect to its neighboring nodes, as shown in Figure 3. To allow the testbed users to experiment with different radio technologies, two different radio frequencies are currently used on our testbed: 2.4GHz (802.11b/g) and 900MHz radios.

- **Back-haul connection.** In addition to the two Ubiquiti
wireless cards, each node is equipped an "Unwired" modem to establish a back-haul link back to NICTA for the purpose of remote management, as shown in Figure 3. Unwired is a Sydney-based metropolitan wireless ISP. The Unwired modem uses a proprietary protocol but claims to be a variant of WiMAX and operates in a licensed 3.5GHz band.

**Connect to traffic controller.** A pair of power-over-Ethernet adapters are used to connect the node to a traffic controller board in the curbside housing through the powerline. Since the traffic controller board sends and receives data via a serial interface, a serial-to-IP conversion is required for the communication between the dummy traffic controller and the testbed (which runs IP).

**II. LINK CHARACTERISTICS**

In this section, we describe some preliminary results of measured link latency from the testbed. First, we observe that the use of 900MHz radio could sometimes introduce a larger latency and a larger variation, as shown in Figure 4. Our hypothesis is that the signal strength level when using 900MHz radio is higher than when 2.4GHz radio is used for the same environment. As a result, a larger number of MAC-layer retransmission occur when 900MHz radio is used. The larger number of MAC-layer retransmissions contribute the higher latency and variations. In other words, there are more packet losses but less MAC-layer retransmissions when 2.4GHz radio is used. However, packets lost in the air were not considered in our latency calculation.

We next examine the efficiency of powerline communication. As shown in Figure 5, given a distance of 100m, the latency of powerline communication is excellent. The average round-delay is about 3.6ms and the variations are very small. In addition, the largest delay for such a distance is less than 8ms.

To understand the expected latency of running management traffic over the Unwired network, we measured the round-trip delay from a machine at NICTA to the mesh node. As shown in Figure 1(a), the average delay of sending traffic over the Unwired network to the mesh node is about 400ms. However, there are a large variation (the delay can be as long as 3 seconds) and significant number of outages. A closer look shows that the delay and outages over the Unwired network are mostly contributed by the wireless link between the mesh node and the Unwired base station. As shown in Figure 1(b), the average delay of the Unwired wireless link is about 200ms. The large delay variations and significant number of outages suggest that a public-shared wireless network like Unwired is not suitable for operating mission-critical applications like traffic control.