LokVaani: Demonstrating Interactive Voice in Lo3

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ABSTRACT

In this work, we consider the goal of enabling effective voice communication in a TDMA, multi-hop mesh network, using *low cost* and *low power* platforms. We consider two primary usage scenarios: (1) enabling a local voice communication within a village-like setting, in developing regions (2) supporting an on-site local communication among a team of users e.g. during emergency response systems.

While there is plentiful literature on the use of TDMA for multi-hop wireless mesh networks, a practical multi-hop TDMA system remains elusive. Our contributions in this regard are three-fold. (1) We demonstrate the working of an 802.15.4-based **lo**w-cost, **lo**w-power, **lo**cal communication system (referred as Lo^3) using custom made handsets and off-the-shelf platforms. (2) We show the practicability of LiT: a *full-fledged* TDMA-based multi-hop, multi-channel MAC protocol for real-time applications; especially on resource constrained platforms, (3) We present implementation-based evaluations results of LiT and show that our protocol achieves practical synchronization, and robust operation in the face of wireless packet errors. As the part of the demo, we showcase *LokVaani*: an interactive voice application for local communication with the help of Lo^3 prototype.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Centralized networks, Wireless communication*

General Terms

Design, Experimentation

Keywords

802.15.4, TDMA-based multi-hop MAC, Voice applications

1. INTRODUCTION

In this work, we consider the goal of enabling effective voice communication in a multi-hop wireless mesh network, especially using *low cost* and *low power* platforms. To achieve this goal, we envision Lo^3 [1], a **lo**w-cost, **lo**-power, **lo**cal communication system using 802.15.4 technology. In Lo^3, we wish to enable applications such as two-way interactive voice, stored voice messaging and community alerts. Such a system can be viewed as a PABX (private automatic branch exchange), for use within a village. This system can also be used to support an on-site local communication among a team of users e.g. during emergency response. The use of mesh network helps reduce the cost of the network and we envision the overall infrastructure cost to be about U.S.$1-2K (Sec. 3).

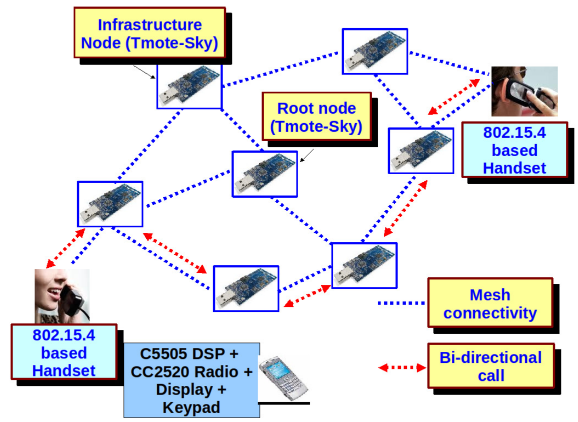

Figure 1: LokVaani: Demonstrating an interactive voice in Lo^3

While 802.15.4 is most appropriate for Lo^3, it was originally designed for embedded wireless messaging and it is quite challenging to enable an effective voice communication on low data rate (250Kbps), duty cycled resource constained platforms. In this regard, our work makes following contributions.

• Importantly, we demonstrate the working of an 802.15.4 based Lo^3 prototype through custom-made handsets and off-the-shelf Tmote-Sky platforms.

• We show the practicability of LiT: a *full-fledged* TDMA-based, centrally-controlled, multi-hop, multi-channel MAC protocol for real-time applications; especially on resource constrained platforms.

• We present implementation-based evaluations results of LiT and show that our protocol achieves practical synchronization, and robust operation in the face of wireless packet errors, while having minimal control overhead.

As the part of the demo, we showcase *LokVaani*: an interactive voice application for local communication with the help of Lo^3 prototype. As shown in Fig. 1, we establish a two-way interactive voice call using 802.15.4-enabled mobile handsets. The call is routed through a multi-hop mesh network. The nodes in the network run the LiT MAC protocol.

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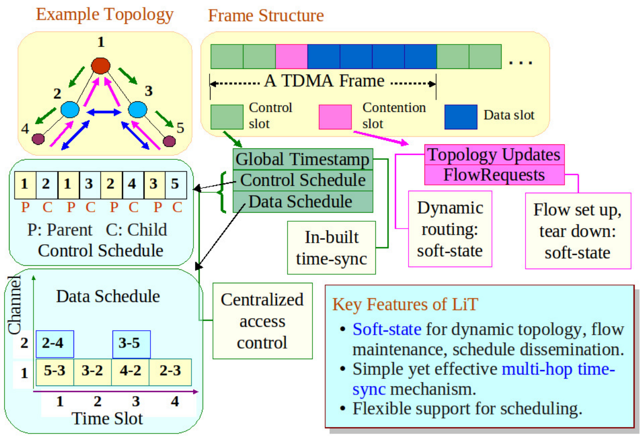

Figure 2: Design of LiT

To our knowledge, ours is the *first* system to demonstrate the working of a wireless multi-hop TDMA system for real-time applications.

2. DESIGN OF THE LIT MAC

What is challenging in the design of LiT? We have to support real-time (and non real-time) applications for Lo^3, in the face of several non-trivial requirements: (1) built-in time-synchronization (2) dynamic routing (3) dynamic flow setup and tear-down (4) flexibility in accommodating scheduling algorithm (5) robust and graceful handling of wireless errors (6) duty-cycling support.

Fig. 2 describes how LiT is designed to address the above requirements. There are four important design choices in LiT which enable its practical implementation. (1) LiT is **TDMA-based**. A TDMA system provides good support for scheduling and duty-cycling over multi-hop mesh networks. As shown in Fig. 2, the TDMA MAC frame has three-types of slots, *control* for broadcasting the schedule information in the network over multiple hops, *contention* for infrequent routing and flow-set-up messaging and *data* for carrying data (voice) packets end-to-end. (2) LiT is **centrally controlled**, which lends itself to a simpler design for coordinating network tree (routing), time-slots and multiple channels (scheduling) as compared to a distributed approach, especially in a multi-hop network. Fig. 2 shows a centrally computed control schedule and data schedule for broadcasting over multiple hops. (3) LiT is **multi-channel** capable which gives better throughput than single channel, if the channel coordination can be done efficiently. Our centralized-TDMA-based approach eases the issue of multi-channel coordination significantly. The same slotting mechanism used by the TDMA mechanism is also used as the granularity of any channel switching (i.e. slot level switching). (4) LiT is **connection-oriented** which means that a higher layer can use it only after a connection formation phase. With central control, the connection formation phase is used to specify the time-slot and channel of operation of each node in a data flow path.

Apart from these choices, LiT makes extensive use of **soft-state** based mechanisms for maintaining network state and handling wireless errors gracefully. Soft-state is especially used to avoid inconsistencies in schedule dissemination over multiple hops that may arise due loss of schedule packets and to maintain routing state at the root to handle node failures gracefully. In our evaluation, we have found that such a soft-state based approach has minimal overhead while being effective.

3. LOKVAANI: DEMONSTRATING INTERACTIVE VOICE

We now describe the set up of *LokVaani* for demonstrating interactive voice in Lo^3 system. Lo^3 has two types of nodes (1) *infrastructure* nodes which serve as intermediate nodes for broadcasting control packets and supporting data flows (2) *handset* nodes which originate voice calls[1]. The network activities are centrally-controlled by a special infrastructure node, *root*. For infrastructure nodes, we employ 802.15.4 based Tmote-sky platform which uses an MSP 430 micro-controller and CC2420 radio. It runs TinyOS (v2.1.0) software platform. Our initial experimentation showed that the Tmote-sky platform is not powerful enough to handle voice processing for implementing handset functionalities. Hence, for handset nodes, we have built a custom handset using TI-based C5505 USB stick module. In our handset, we interfaced this C5505 module with the 802.15.4 compliant CC2520 radio. The C5505 USB stick module has a TMS320VC5505 DSP (100Mhz CPU, 320 KB RAM) which effectively supports voice processing. The stick also has a AIC 3204 codec chip which enables voice input and output functions. The voice sampled by AIC 3204 at 64kbps is encoded into a 5.9kbps voice stream using a *Speex* implementation on the C5505 DSP platform.

We now describe the working of *LokVaani*: an interactive voice in the Lo^3 prototype which will be shown in the demo. As shown in a sample set up in Fig. 1, out of 9 nodes, 7 nodes are used as infrastructure nodes and 2 nodes as handsets. LiT TDMA MAC is implemented on all the nodes. We set the TDMA frame length to be 60ms (approx) comprising of 1 control slot of 12ms, 1 contention slot of 10ms and 4 data slots, each of 9ms (approx). Now, we enable a two-way interactive voice between two 802.15.4 handsets. The 5.9kbps Speex codec generates 15 bytes every 20ms. Thus, the 45 byte packets generated every 60 ms by the source are transmited to destination over multiple hops in the network.

We thoroughly evaluated LiT on a 19-node testbed. To quantify the performance of time synchronization mechanism (important for any TDMA system), we measure the *relative clock drift* between the sending and receiving nodes. This value is largely 1 or 2 ticks (1 tick corresponds to $30.5\mu s$) over 30 second period which is quite effective . Next, we measure the usage of the contention slots over multiple hops (since contention slots are used for call set-up). The usage is mostly less than 2% leaving enough contention slots for use. The worst-case flow-set-up latency is 2 sec which is very much tolerable in practice. The data-path delay (which is function of number of hops) is mostly less than 300ms. The average jitter in data-path is also quite small (1-2ms) leading to a MOS socre of 3.8 (considered good in practice). These results demonstrate the suitability of LiT for real-time voice.

4. REFERENCES

[1] B. Raman and K. Chebrolu. Lo^3: **Lo**w-cost, **Lo**w-power, **Lo**cal Voice and Messaging for Developing Regions. In *NSDR'09*, Oct 2009.

[1]Handset nodes never serve as intermediate nodes.