IST-754
Capstone Project in Telecommunications:
Cost Modeling and Analysis

Final Project

VoIP on Mesh Networks

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May 7th, 2004

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Introduction

The development of wireless communication has been very fast in the last couple of years. Today the industry demands mobility functionalities on every node. Scenarios such as emergency situations, rescue and disaster operations, and connectivity in remote areas with no possibilities of physical infrastructure, are some examples of environments in special need for independent communication applications with no central point of coordination.

Limitations of wireless network infrastructures to extend the functionalities of nodes in areas where no central point is present or areas not covered between two central points suggest that the incorporation of communication functionalities on the node itself would be necessary.

The purpose of this study is to build a cost model for Saint Lucia to deploy a VoIP system running on a mesh network. We will be using a specific technology, LocustWorld, so we will analyze the feasibility of deploying such a technology to a small environment. Then we will extend these results to a larger scale and for real communities. Through our study we will try to answer the following questions:

- What is the performance when transmitting voice and data simultaneously? (Packet transmission, end-to-end delay, etc.)
- What are the requirements in terms of protocols and/or standards for the system to perform?
- How would hand-off affect transmission of voice and/or data packets?
- What are the consequences for VoIP transmission when different mesh protocols are working together?
- What happens when the maximum number of simultaneous users per AP is reached?
- Would this technology be the solution to WLANs limitations?

Methodology

First it was developed a review of LocustWorld documentation and their technology to get familiar with it and determine the most important parameters that characterize it. While doing that, other literature about mesh networks, routing protocols, and Voice over the Internet Protocol (VoIP) was studied as well as other mesh solutions in order to have a better understanding of LocustWorld technology. Then it was drawn some ideas about what types of tests would be done. After determining how LocustWorld mesh software works, it was downloaded and installed in laptops that were going to serve as mesh nodes. Machines that were going to serve as regular Windows clients were configured to participate in the mesh network in order to perform the test. Knowing that they could get connected and able to even browse the Internet was fundamental to continue with the next step, the test.

The test itself took more effort and time given the limitations of the tools available to perform VoIP tests and that were able to capture transmissions on the mesh network. Finally, the selected software was NetIQ Chariot. The way the test was performed can be found in the section with the same title.

Literature overview

In order to understand LocustWorld technology we have to study the general concepts and characteristics of ad-hoc and mesh networks. Being one of the main characteristics of LocustWorld technology the use of Ad-hoc On-demand Distance Vector **(**AODV) as its routing protocol, we have to explore it as well. And finally given that our model is the provision of Voice over the Internet Protocol (VoIP) through mesh networks for a community, we will include some VoIP measurements and explanations while reviewing the tests results.

Mobile Ad-hoc networks

The Internet Engineering Task Force (IETF)'s Mobile Ad-hoc Networks (MANETs) Working Group has the main goal of standardizing the IP routing protocol for wireless applications within both static and dynamic topologies. Due to the fundamental design issues that the wireless link interfaces have with some unique routing interface characteristics, and because node topologies within a wireless routing region may experience increased dynamics, due to motion or other factors, there can be many different MANETs.

However, in general terms a mobile ad-hoc network (MANET) is defined as "a collection of autonomous nodes or terminals that communicate with each other by forming a multi-hop radio network and maintaining connectivity in a decentralized manner" (Wireless Communication Technology Group, National Institute of Standards and Technology, [18]).

The control of the network is distributed among all nodes because all of them have router and host functionalities, including discovering the topology and delivering messages. Therefore, the network topology is dynamic with new nodes getting connected, some being disconnected, and some others moving around – entering the range of other nodes and / or moving away. This type of arrangement requires efficient routing protocols that govern communication between all nodes in a multipath environment where nodes can have several options to get to a particular point. The algorithms will assure that network resources are being used in an effective way by controlling network organization, scheduling, and routing.

In theory some technical benefits of mesh networks include capabilities such as self-forming – as new devices are added to the network, it will detect them automatically and expand the coverage area accordingly; self-healing – the network automatically reroutes network traffic when a device fails; and self-balancing – the network finds the optimum path for network traffic and balances the load across the network [20].

Due to the nature of wireless communication, ad-hoc nodes also have to deal with issues such as link quality, propagation path loss, noise, fading, interference, and reduced bandwidth. Other constraints include power source limitations and the highly dynamic environment that increases the level of complexity of these networks. This last element constitutes the biggest challenge of mesh networks given the change of topology as nodes moves around.

Given the evolution of MANETs, a classification based on routing protocols has been developed over the years by the IETF. This classification includes the Dynamic Source Routing Protocol (DSR) which is specified in RFC (2026), the Ad-hoc On Demand Vector (AODV) in RFC (3561), the Optimized Link State Routing Protocol (OLSR) RFC (3626), and the Topology Broadcast based on Reverse-Path Forwarding (TBRPF) RFC (3684).

LocustWorld mesh technology

LocustWorld technology uses wireless networking and mesh routing to build self organizing networks that can transport any IP service over multiple hops. This solution complies with all the characteristics previously discussed about ad-hoc mobile networks, with the particularity of being a multi-hop network based on AODV. As other mesh networks, in this technology mesh nodes are able to route between many other nodes, building a widespread network with multiple routes. LocustWorld solution is based on its MeshAP software, which can be downloaded freely and run on PC compatible equipment. With this software, users would be able to start building mesh networks. However, in order to build stronger and scalable networks, as it will be explained later, users should install the LocustWorld mesh router or MeshBox, which is a dedicated router device, preloaded with the MeshAP.

How does it work?

- Using a CD that contains the software, every user becomes a member of a Mesh Network. With only one user connected to the Internet, all the others can have access as well.
- The network is peer-to-peer. When a user is out of range, packets hops between nodes to get the destination. The system does not provide security.
- **Operation:** device boots software and allocates an IP address. It tries to find an internet gateway. If it does not find it, it gets as a repeater-cell, initiating an internal DNS and DHCP service. The kernel AODV is loaded. Cells that are gateways broadcast a route, which is taken by no gateways to establish a “compressed encrypted IP-tunnel VPN” for traffic transmission [12].

Given that LocustWorld mesh networking technology is based on AODV, we will explain its process of discovering nodes and how the routing table is updated.

Ad-hoc On-demand Distance Vector (AODV)

To determine the distance to the destination node, every node in the AODV routing protocol uses the hop count, which is the number of hops a packet has gone through from start to end. Each one of these nodes maintains a routing table containing three basic fields – a next hop node, a sequence number, and a hop count. Each node sends packets to the next hop node; then this will send the packet to its next hop node, and so on until it reaches the destination. The sequence number is a time-stamping measurement that indicates the freshness of a route, and the hop count represents the current distance to the destination node [8].

To keep its routing table updated or to discover routes, each node completes a request-response cycle process that involves three messages: RREQ, RREP, and RERR. First, a node broadcasts an RREQ message to all its neighbors in order to get a route. Any node receiving the RREQ and not having a route to the requested destination will in turn broadcast the RREQ message, so will it remember a reverse-route to the requesting node that will be used to forward the responses to the RREQ. The process continues until a valid route is found, so this node responds with an RREP message, consisting in a unicast message that will be sent all the way through the reverse-routes of each intermediate node until it gets the original requesting node. Consequently, the bidirectional route between these nodes is included in the routing table of the requesting node. In case the node loses connectivity to its next hop, it sends an RERR message to all the possible nodes that have received its RREP so that they invalidate the route [8].

Problem formulation

Providing remote areas with telecommunication services has been a major concern in several countries all over the world. The high costs of building infrastructures to connect these areas which usually are characterized by hills, dense vegetation, low family income, and low population density, make prohibitive the possibility of providing high speed Internet connections and in some cases even voice communication services.

In developing countries these kinds of problems have even larger effects given the low capabilities of governments to invest in telecom infrastructures not only in remote areas but also even in urban areas. In most cases, private service providers do not invest there because they are not willing to face risks that usually are much higher than the possible return on investment or because the cannot afford to sustain these services. Nowadays that broadband internet access is becoming a critical resource for business, education, and personal communications, these regions are getting far behind being disconnected from the rest of the world.

Several studies have suggested the possibility of using wireless LANs as a low cost and easy to deploy solution, which can be affordable by users as well as by service providers. Wireless LANs are bandwidth limited. As WLANs function mostly in architecture mode with access points as central point of coordination, they divide the bandwidth between all the devices connected to it, which limits connection availability. One of the main problems of wireless LAN technologies, however, is its short range. They have been limited to provide extension of wired network services to building or maybe campuses, so they do not offer a feasible solution for remote area communities.

As it has been discussed earlier, the main advantage of using mesh networking is that the short range of wireless LAN can be eliminated because as new nodes are added to the network it dynamically extends to a wider wireless network. This is a big advantage when the range of a single access point cannot cover large areas, which is the most likely environment in remote areas. Therefore, as a broadband link brought to these areas through a satellite, leased line, or microwave connection, a mesh network would be capable of delivering wireless broadband services at low cost with an excellent coverage that will smoothly increase as new nodes are incorporated. Due to its self organizing capabilities, mesh networks grow as complex and extensible networks without high programming and support requirements. Not to mention, the advantage of being able to reach every corner as needed as packets will hop through different routes until reaching its destination, which at the same time increases resilience.

Our theory suggests that LocustWorld Wireless Mesh can be a feasible solution to deliver affordable rural broadband services by sharing Internet connections especially in environments as described before. Being this solution based on open source, it can be freely used; it does not require higher knowledge about networks or device configurations, and it can be used with fairly cheap devices (computers and routers). We should determine the level of interoperability with different devices that LocustWorld technology offers so that users or service providers are not limited to particular vendors as well as to ensure users can roam smoothly throughout the coverage area. Finally given that our intention is to provide VoIP to these communities, the system should be able to handle VoIP requirements.

Why wireless mesh?

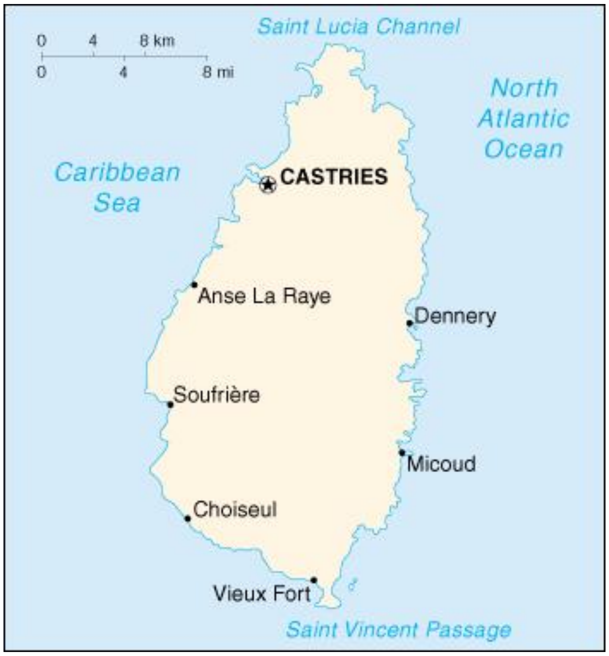
Web (2003) notes that even though security is a big issue with mesh networks mainly due to its wider area, they provide many more advantages over pure wireless LANs:

- Larger coverage area than wireless LAN technologies. Mesh networks expand the coverage area as more devices are added to the network. Each node can establish peer-to-peer connections anywhere, anytime.
- Multi-hop systems, providing redundant paths. Packets hop from node to node until they get their destination.

- They are low-power; only the necessary power to get to neighboring nodes, which also reduces interference.
- They operate at shorter paths, getting less noise, and thus better bandwidth.

Saint Lucia's situation

The total land area of Saint Lucia is 616 sq km (41 km long and 20 km wide). The most populated regions, which include Anse-La-Raye, Soufrière, Choiseul, Laborie, Vieux-Fort, Micoud, Dennery, Gros-Islet, and the capital city Castries, are located along the coastline, while the interior of the island is extremely mountainous.



In addition to the problems been described earlier, Saint Lucia's limited telecom infrastructure increases communication problems within the country, including voice and data, and makes the availability of Internet connections cost prohibited.

The challenge

Ideally the model would be every node to have routing capabilities so that the network expands as nodes get connected. Every one of these nodes would serve as an aggregation point of signals for other nodes to have connectivity, which will provide connectivity for others as well. Figure 1 is a fully functional mesh network with all the features and advantages of a dynamic network that easily increases in size.

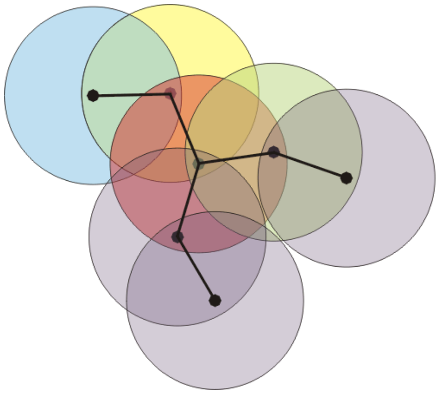


Figure 1 - Mesh network expansion

Using LocustWorld technology, the process to create this environment should be simple. Every device or computer connected to the ad-hoc network would need to be running the LocustWorld mesh software. In this way every device in the network is a mesh node that would serve others to get connected, expanding the network dynamically.

Neither the process nor the technology is as simple as it seems. The first constraint is the technology itself. LocustWorld provides only the boot file that allows people to start their devices as mesh nodes. When the computer boot using this file, it gets in a Linux environment, so there is no way to install other applications on the computer for people to use while they are connected. Not to mention the lack of familiarity of most computer users with Linux environments. The fact that Windows is the de facto operating system used today, and thus the high switching costs that Windows has over Linux environments limit LocustWorld solution acceptance at mass level.

These issues bring about three possible ways to deploy a VoIP system using LocustWorld technology.

- Each home user would have two computers, one as mesh node and one as a Windows client. This Windows client gets the signal from the mesh node, so users can browse, perform VoIP, and use other applications. The computer working as mesh node can be a fairly cheap computer which must be on all the time so that the network can preserve shape, grow as other nodes are included, and provide continuous connectivity for other nodes in the neighborhood. There are two issues in this scenario. First, there has to be always one computer wirily connected to the broadband connection so that it can be extended to the wireless users in the mesh network. Second, given that the mesh nodes are computers, they should be close enough to each other so that signals can reached and range maintained. In this case users would have several ways for VoIP. Using the Windows client, this computer should be provided with a headset as well as a VoIP application. There are many freeware options that could be installed. Another option would be adapting IP phones to the mesh node.
- There are permanent mesh boxes throughout the city to provide connection to home and business users. Users have one computer configured as a mesh node that gets broadband connection through the closest mesh box and serves as an extension of the signal to other mesh nodes around it. Even though users can browse on the web, they are limited to a Linux environment that does not allow them to user their computers for other purposes. In order to user VoIP they need to connect an IP phone to their mesh node.
- There are permanent mesh boxes throughout the city to provide connection to home and business users. Users are configured as regular Windows clients, so it eliminates the constraint of limited Linux environments for end users. The disadvantage is cost given that there should be enough boxes to provide connection to every user within its range. Every box should be able to connect to all the boxes around it in order to keep connectivity all the time. In this case the network does not grow as new users are added in the network because they do not have routing capabilities to extend the network range to other users as they are configured as regular Windows clients.

These three environments give us an idea of options that we must evaluate in order to provide Saint Lucia's communities with VoIP services through broadband connections to the mesh network. In order to perform such an evaluation, in the next section, we show how LocustWorld could be evaluated. Even though the tests were performed in a small scenario, which is most likely to the first one described above, the results can perfectly be extended to the other scenarios as well.

Testing

Objective:

- Evaluate the performance of VoIP transmission in a multi-hop multipoint-to-multipoint environment using MeshAP software from LocustWorld, which is based the Ad-hoc On Demand Distance Vector (AODV) protocol.

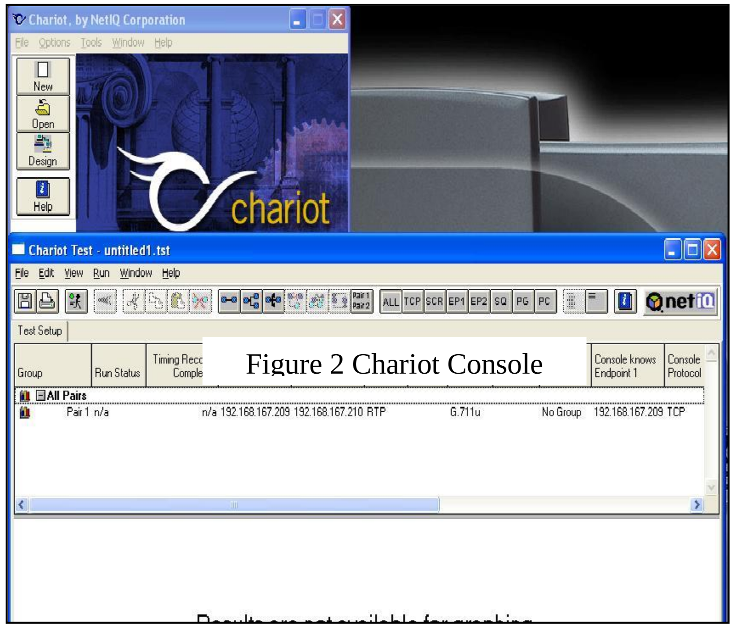


Figure 2 Chariot Console

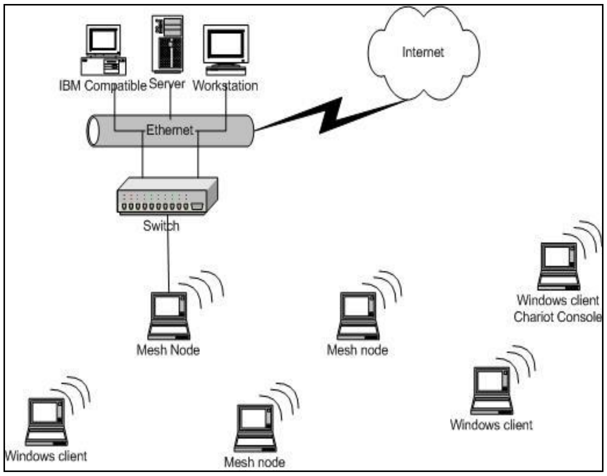
Tools:

- **Hardware:** eight laptops, three Orinoco wireless cards, five Cisco wireless cards.
- **Software:** Mesh Software, Chariot console software, Chariot endpoints software, wireless client drivers.

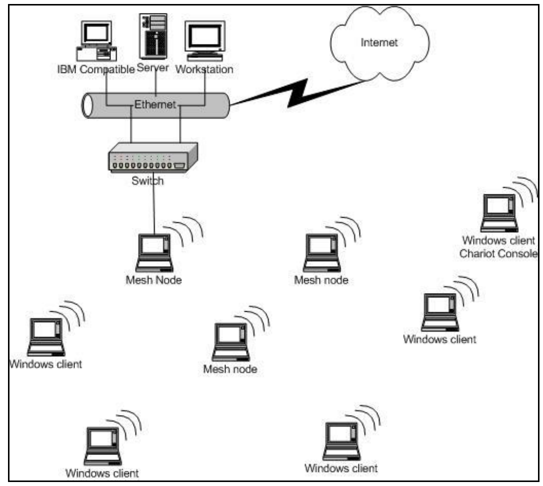
Scenarios:

With this set of tools, a substantially interesting scenario could be deployed, which will allow us to reach the objective of this test. As the main goal is to evaluate the performance of mesh networks, two scenarios were deployed, both using the mesh network as a mean of communication. Therefore, always there is a mesh consisting of three computers serving as mesh nodes, where one of them connected is to a switch to the wired network to provide Internet connection. Also connected to the mesh network there is one Windows client which contains the Chariot console to measure the performance of the voice transmission.

In the first scenario two Windows clients are connected to each side of the mesh network so that they can transmit packets between them crossing the mesh nodes. The second scenario simulates how the network would perform as it grows. There are four Windows clients using the mesh network to communicate between each other. Even though there is permanent http service and email available, in both scenarios the only application running for the test is VoIP. These tests simulate the case of using VoIP through software applications installed in the clients.



Scenario 1



Scenario 2

Limitations

Given the limitations of equipment, we were not able to increase the number of clients in order to identify degradation levels in which VoIP conversations cannot be handled anymore. These types of sensitivity analyses would allows us to decide the quality levels we would set per mesh box based on the maximum number of simultaneous conversations.

Outcomes

There are nine tests, including the change of directions. The first two tests is the case of only two clients having a conversation. Tests three and four are also with two clients and one conversation, but increasing the distance between them. Tests five and six have a different setting in which the mesh nodes where dispersed as well as the two clients. Tests seven and eight were done in the same configuration as test five and six but with two more clients for two simultaneous conversations. Finally test nine is one conversation under Quality of Service (QoS). For more accurate results, the tests were run several times.

When evaluating VoIP using Chariot, there are several measurements that can analyzed every time the test is run, among them throughput, Mean Opinion Score (MOS), end to end delay, one way delay, RFC 1889 Jitter average, lost data, and jitter - delay variation. For the effects of our previously described objectives, we evaluated only three of these measurements, (MOS), two way delay, and jitter, which are shown below.

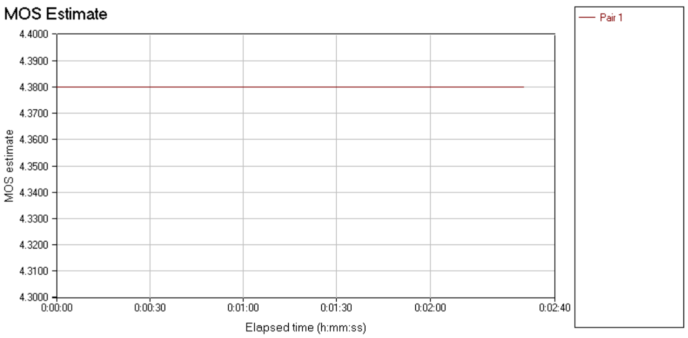
Mean Opinion Score – MOS

MOS is a measurement especially important for voice equipment being used for telecommunications companies to determine call quality. Some prefer to use the "E-model" (ITU G.107), which is a complex formula that calculates a single score called the "R factor". However, both measurements the R factor and the estimated MOS are related, so there is no problem using one or the other. R factor values range from 100 (excellent) down to 0 (poor) whereas a MOS can range from 5 down to 1. To give an idea of this relation, some values of both measurements are shown in the following table.

R	User Satisfaction	MOS
100 - 94	Very Satisfied	5.0 - 4.4
90 - 80	Satisfied	4.3 - 4.0
79 – 70	Some users dissatisfied	3.9 - 3.6
. . .		. . .
0 – 50	Not recommended	1.0

Table XX – Relation between R and MOS measurements

Two clients – one conversation



Same test - Opposite direction

Increasing the distance, two clients – one conversation

Same test - Opposite direction

Four clients – two simultaneous conversations

Same test - Opposite direction

The first and second test shows an excellent and steady MOS value either way, calling both directions, which would confirm that both users have a good experience during their calls. In the third and fourth test, not only does the graph show variances in the MOS values when the call starts from different points, but it also shows high and low MOS values during a call. These high and low values could be bad if they prolong for a long period, which is not the case in the test. The seventh and eighth test shows interesting results. Even though there are two simultaneous conversations, the results of the worse pair (conversation) are almost equal to the previous test of only one conversation. This is a good finding because it shows that not necessarily the quality will degrade for an increase in the number of simultaneous conversations, yet there will be a limit in the number of conversations crossing the same mesh nodes at one particular time.

Two-Way Delay

Two-way delay is another good measurement to take into account in any VoIP analysis because conversations start in one point and finish in another, so two-way delay measures the total delay during a conversation. Although our literature indicates 200 to 300ms as acceptable values for round trip delay, our acceptable values for these tests will be up to 100ms. NetIQ Chariot generates graphs only for one way delay, which are shown below. They totalize four delay components. Propagation delay, the physical distance between the two ends; Transport delay, time for packets to go through networking devices within the network; Packetization delay, time for codecs to transform packets from analog to digital and vice versa; and Jitter buffer delay, time packets wait to be converted by codecs. For all the tests, G.711 was the codec used because is the fastest one performing packetization at one millisecond for 64 Kbps data rates.

Two clients – one conversation

Same test - Opposite direction

Increasing the distance, two clients – one conversation

Same test - Opposite direction

Same test - Opposite direction

Four clients – two simultaneous conversations

The graphs show that there would not be any problem in terms of delay when transmitting VoIP packets in this type of environment. Every test run shows results below 100ms which is our point of reference. It is important to point out, however, that delay would vary according to the configuration of the network, and the equipment and codecs used.

Jitter

The variation in packet delay is sometimes called "jitter". This term, however, causes confusion because it is used in different ways by different groups of people. The first meaning is the variation of a signal with respect to some clock signal, where the arrival time of the signal is expected to coincide with the arrival of the clock signal. This meaning is used with reference to synchronous signals and might be used to measure the quality of circuit emulation, for example. There is also a metric called "wander" used in this context. The second meaning has to do with the variation of a metric (e.g., delay) with respect to some reference metric (e.g., average delay or minimum delay). This meaning is frequently used by computer scientists and frequently (but not always) refers to variation in delay. The following graphs shows jitter as the variation in interarrival time for RTP (real-time transport protocol) data packets.

Two clients – one conversation

Same test - Opposite direction

Increasing the distance, two clients – one conversation

Same test - Opposite direction

Four clients – two simultaneous conversations

Same test - Opposite direction

These graphs confirm that the calls' quality is acceptable for all the tests as we see all the Jitter values under 50ms, which is a good point of reference for this measurement for data networks transmitting VoIP packets.

Quality of Service (QoS)
In this section we show the results of the same tests incorporating QoS in order to determine how the network would perform, although they were performed only for two clients and one conversation.

MOS

One-Way Delay
Jitter

Comparing these results with the previous for one conversation (cases three and four), we can see similar results in almost all measurements, which was expected given that QoS is almost imperceptible for low loads. However, it is highly recommended for larger deployments such as the one in discussion in this document.

As it is shown below in the summary table, the results of these tests demonstrate that VoIP is definitely technically feasible in a mesh environment. Even though these are lab tests which are close to perfect conditions – maximum distance between nodes and Windows clients is ten meters, not a very congested network, and lack of other applications running simultaneously; they give us a good insight of the transmission behavior in a mesh network for VoIP packets.

Summary of results

		Average One Way delay (ms)	Average End-to-End delay (ms)	MOS	RFC 1889 (ms) Jitter	Jitter max Delay variation (ms)
1	1 conversation	3	44	4.38	0	21
2	opposite direction	2	43	4.38	1.3	18
3	1 c - 1 client out	2	43	4.38	0.86	12
4	opposite direction	3	44	4.24	1	89
5*	1 c - 1 client + mesh node out	41	82	4.38	8.72	605
6*	opposite direction	304	304	1.81	23.69	12386
7	2 conversations	8	49	3.72	2.611	176
8	opposite direction	12	53	4.38	0.68	667
9	1 conversation - QoS	1	42	4.38	0.2	98

Table 1 – Summary of tests results

* Note: although these tests are presented in the table, they were eliminated given that one of the mesh nodes went down for lack of energy. They were kept just as an example of the negative effects the network can have when one of the mesh nodes is not working properly.

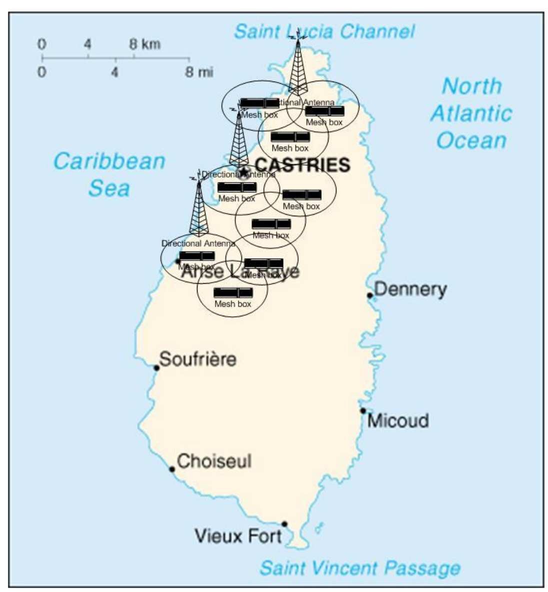
Analysis
In the previous section some of the factors that affect VoIP quality were introduced such as delay and jitter as well as their values for the described scenarios. Another element is analyzed to determine if the network can handle VoIP is packet loss, which in every test run was less that five percent. Therefore, it is a fact that the system is capable of supporting VoIP services. To continue the analysis of this deployment we must study a crucial factor for VoIP service, bandwidth. Walker (2001) recommends bandwidth per each VoIP conversation of 160Kbps when using G.711 and 50Kbps for other codecs. However, these values seem to be too high. Generally speaking we know that the telephone service uses 64Kbps per call, so if we can afford this value for upstream and downstream, we can guarantee good quality. Now with the use of compression algorithms, recognized broadband phone companies are usually using even less bandwidth. Packet8 claims that their system uses only 17Kbps of total data throughput, upstream and downstream per each active voice line. In general, Vonage requires 90Kbps of upload and download, yet through a bandwidth saver mechanism, they ask for only 30Kbps for call.

In a bandwidth-constrained environment such as the one we are dealing with, we must determine the best possible use of bandwidth for multiple tasks. However, we will use the worse case, 160Kbbps per call. Since the system works with 802.11b cards and assuming a throughput of 5Mbps, the maximum number of concurrent calls per mesh box would be fifteen. These values would help us later to determine the number of mesh boxes per sq km that need to be installed in order to provide the service.

Cost Model

Assumptions

- Mesh AP is provided with an Omni directional antenna of 400m range
- There are two PSTN aggregation points, one in Castries and one in Vieux Fort, from where to distribute the services.
- Population is distributed uniformly



The cost model has been developed only for the most populated regions identified in Saint Lucia: Anse-La-Raye, Soufrière, Choiseul, Laborie, Vieux-Fort, Micoud, Dennery, Gros-Islet, and the capital city Castries. Since the interior of the island is extremely mountainous, these regions have been excluded from the analysis of such a deployment. Anther element that was considered for the deployment was population density. The total population of Saint Lucia is approximately 160,000 with around a total of 50,000 households, so cities with population density below 150 people/sq km were not included because the cost-benefit of this deployment would be too low.

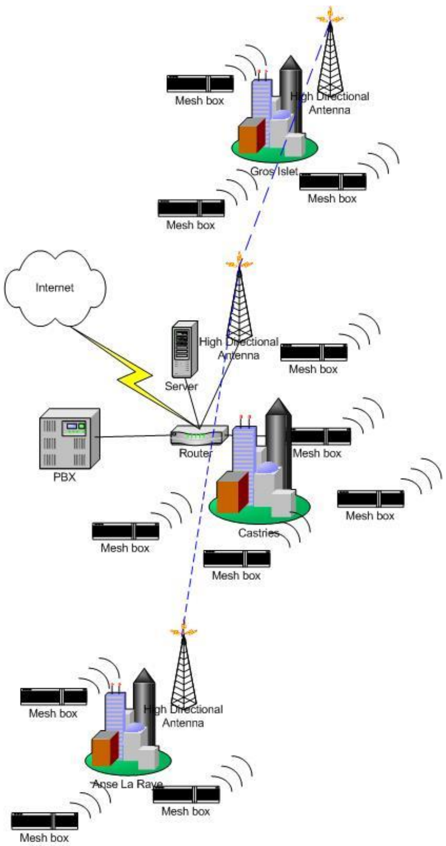
The model would be Cable & Wireless, only fixed service provider, to install the entire system and provide the service. Deployment would be in three phases as described below according to the closeness of regions so that the initial costs are spread out while start collecting some revenues. Moreover, this model would also allow the provider to have a smoothly deployments in the other regions based on its previous experience.

- First year: Anse-La-Raye, Castries, and Gros-Islet.
- Second year: Soufrière, Choiseul, Laborie, and Vieux-Fort.
- Third year: Micoud and Dennery.

Because we are suggesting VoIP over mesh networks, it would be necessary a very high reliable network that includes a number of mesh boxes based on the assumption that 30% of the households per sq kilometer would have simultaneous calls. We based our calculations on the assumption that families are 5-member. The following table shows the details of these calculations, including the number of mesh boxes per sq kilometer in each city.

Saint Lucia Mesh Network for VoIP HARDWARE					Deployment first year	
Aggregation Points						
	Area (sq km)	Population Density per sq km	Estimated households sq km	Concurrent calls sq km	Mesh box per sq km	Total Mesh box
1st year						
Anse-La-Raye	46.9	127	25	8	1	24
Castries (capital)	79.5	817	163	49	3	260
Gros-Islet	101.5	207	41	12	1	84
2nd year						
Soufrière	50.5	153	31	9	1	31
Choiseul	31.3	197	39	12	1	25
Laborie	37.8	196	39	12	1	30
Vieux-Fort	43.8	340	68	20	1	60
3rd year						
Micoud	77.7	208	42	12	1	65
Dennery	69.7	185	37	11	1	52

The proposed architecture of the VoIP system over a mesh network involves the elements in the graph below. There is a high directional antenna (24dBi) in each of towns of the deployments communicates with directional antenna in Castries - main C&W infrastructure, and which increases reliability. Mesh boxes are SIP equipped, while the VoIP system works as a gateway and call processing. Sitting between the PSTN network and the VoIP system there is a switching controller.



Installation, equipment, and operation costs for C&W to build the system and offer the service are described in the following tables.

Saint Lucia Mesh Network for VoIP HARDWARE - 1st year			
Aggregation Points	**Units**	**Price**	**Total**
Anse-La-Raye			
LocustWorld Mesh Box	24	$ 300.00	$ 7,147.56
Weatherproof cabinet	1	$ 99.33	$ 99.33
Lightning Arrestor	24	$ 40.00	$ 953.01
High gain antenna (24 dBi)	1	$3,000.00	$ 3,000.00
Switching controller	1	$ 500.00	$ 500.00
VoIP system (server and software)	1	$3,500.00	$ 3,500.00
Router	1	$ 500.00	$ 500.00
Subtotal			**$ 15,699.90**
Castries (capital)			
LocustWorld Mesh Box	260	$ 300.00	$ 77,941.80
Weatherproof cabinet	1	$ 99.33	$ 99.33
Lightning Arrestor	260	$ 40.00	$ 10,392.24
High gain antenna (24 dBi)	1	$3,000.00	$ 3,000.00
Switching controller	1	$ 500.00	$ 500.00
VoIP system (server and software)	1	$3,500.00	$ 3,500.00

Router	1	$ 500.00	$ 500.00
Subtotal			**$ 95,933.37**
Gros-Islet			
LocustWorld Mesh Box	84	$ 300.00	$ 25,212.60
Weatherproof cabinet	1	$ 99.33	$ 99.33
Lightning Arrestor	84	$ 40.00	$ 3,361.68
High gain antenna (24 dBi)	1	$3,000.00	$ 3,000.00
Switching controller	1	$ 500.00	$ 500.00
VoIP system (server and software)	1	$3,500.00	$ 3,500.00
Router	1	$ 500.00	$ 500.00
Subtotal			**$ 36,173.61**
TOTAL 1st YEAR			**$ 147,806.88**

Saint Lucia
Mesh Network for VoIP
HARDWARE - 2nd year

Aggregation Points	**Units**	**Price**	**Total**
Soufrière			
LocustWorld Mesh Box	31	$ 300.00	$ 9,271.80
Weatherproof cabinet	1	$ 99.33	$ 99.33
Lightning Arrestor	31	$ 40.00	$ 1,236.24
High gain antenna (24 dBi)	1	$3,000.00	$ 3,000.00
Switching controller	1	$ 500.00	$ 500.00
VoIP system (server and software)	1	$3,500.00	$ 3,500.00
Router	1	$ 500.00	$ 500.00
Subtotal			**$ 18,107.37**
Choiseul			
LocustWorld Mesh Box	25	$ 300.00	$ 7,399.32
Weatherproof cabinet	1	$ 99.33	$ 99.33
Lightning Arrestor	25	$ 40.00	$ 986.58
High gain antenna (24 dBi)	1	$3,000.00	$ 3,000.00
Switching controller	1	$ 500.00	$ 500.00
VoIP system (server and software)	1	$3,500.00	$ 3,500.00
Router	1	$ 500.00	$ 500.00
Subtotal			**$ 15,985.23**
Laborie			
LocustWorld Mesh Box	30	$ 300.00	$ 8,890.56
Weatherproof cabinet	1	$ 99.33	$ 99.33
Lightning Arrestor	30	$ 40.00	$ 1,185.41
High gain antenna (24 dBi)	1	$3,000.00	$ 3,000.00
Switching controller	1	$ 500.00	$ 500.00

VoIP system (server and software)	1	$3,500.00	$ 3,500.00
Router	1	$ 500.00	$ 500.00
Subtotal			**$ 17,675.30**
Vieux-Fort			
LocustWorld Mesh Box	60	$ 300.00	$ 17,870.40
Weatherproof cabinet	1	$ 99.33	$ 99.33
Lightning Arrestor	60	$ 40.00	$ 2,382.72
High gain antenna (24 dBi)	1	$3,000.00	$ 3,000.00
Switching controller	1	$ 500.00	$ 500.00
VoIP system (server and software)	1	$3,500.00	$ 3,500.00
Router	1	$ 500.00	$ 500.00
Subtotal			**$ 27,852.45**
TOTAL 2nd YEAR			**$ 79,620.34**

Saint Lucia

Mesh Network for VoIP

HARDWARE - 3rd year

Aggregation Points	Units	Price	Total
Micoud			
LocustWorld Mesh Box	65	$ 300.00	$ 19,393.92
Weatherproof cabinet	1	$ 99.33	$ 99.33
Lightning Arrestor	65	$ 40.00	$ 2,585.86
High gain antenna (24 dBi)	1	$3,000.00	$ 3,000.00
Switching controller	1	$ 500.00	$ 500.00
VoIP system (server and software)	1	$3,500.00	$ 3,500.00
Router	1	$ 500.00	$ 500.00
Subtotal			**$ 29,579.11**
Dennery			
LocustWorld Mesh Box	52	$ 300.00	$ 15,473.40
Weatherproof cabinet	1	$ 99.33	$ 99.33
Lightning Arrestor	52	$ 40.00	$ 2,063.12
High gain antenna (24 dBi)	1	$3,000.00	$ 3,000.00
Switching controller	1	$ 500.00	$ 500.00
VoIP system (server and software)	1	$3,500.00	$ 3,500.00
Router	1	$ 500.00	$ 500.00
Subtotal			**$ 25,135.85**
TOTAL 3rd YEAR			**$ 54,714.96**

Saint Lucia
Mesh Network Project
Total Cost of Ownership

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Total	$ 1,021,206.88	$933,420.34	$908,514.96	$861,400.00	$855,800.00	$4,580,342.18
Capital Costs						
Installation Costs						
Hardware	$ 147,806.88	$ 79,620.34	$ 54,714.96			**$ 282,142.18**
Project management	$ 15,000.00					**$ 15,000.00**
Running Costs						
IT Operational Costs						
Hardware replacement		$ 1,000.00	$ 1,000.00	$ 3,000.00	$ 3,000.00	**$ 8,000.00**
Maintenance and support staff	$ 648,000.00	$ 648,000.00	$ 648,000.00	$ 648,000.00	$ 648,000.00	**$3,240,000.00**
Staff fringe-benefit	$ 194,400.00	$ 194,400.00	$ 194,400.00	$ 194,400.00	$ 194,400.00	**$ 972,000.00**
Contingency reserve	$ 2,000.00	$ 2,000.00	$ 2,000.00	$ 2,000.00	$ 2,000.00	**$ 10,000.00**
Staff training	$ 3,000.00	$ 1,000.00	$ 1,000.00	$ 3,000.00	$ 1,000.00	**$ 9,000.00**
Broadband Internet connection	$ 5,000.00	$ 5,000.00	$ 5,000.00	$ 5,000.00	$ 5,000.00	**$ 25,000.00**
Spectrum Licensing	$ -	$ -	$ -	$ -	$ -	**$ -**
Administration Costs						
Budget from the IT Organization	$ 2,000.00	$ 800.00	$ 800.00	$ 2,000.00	$ 800.00	**$ 6,400.00**
Purchase from the IT Organization	$ 2,000.00	$ 800.00	$ 800.00	$ 2,000.00	$ 800.00	**$ 6,400.00**
Procurement from the IT Organization	$ 2,000.00	$ 800.00	$ 800.00	$ 2,000.00	$ 800.00	**$ 6,400.00**

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