Department of Electrical and Electronics Engineering

College of Engineering

University of the Philippines

Masters of Science Thesis Proposal

1.0 Title of Project

Multibeamformer Testbed for Capacity Encancement of 802.11b Networks

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4.0 Abstract

The increasing popularity of wireless local area networks (WLAN) is of no surprise, as the current trend for most communication networks is to go wireless. Although the technology used in WLANs is already advanced, and a great improvement from conventional wireless infrastructures, most access points (AP) still uses "primitive" omnidirectional antennas to handle conversion from an electromagnetic wave in free space to an electric signal that can be processed by the AP circuitry.

This research aims to investigate the advantages/disadvantages of using multibeamformer arrays on WLAN access points over the standard omnidirectional antennas that usually

come default with commercially available APs. The MultiBeamformer Network (MBFN) will allow the antenna array to produce 4 independent beams/channels, where theoretically the AP can switch between these channels to select the channel that will have the highest received power and/or highest capacity while being transparent to the AP itself. In this research, we investigate the performance gains that may be achieved in 802.11b networks by using such multibeamformer networks to provide angle/spatial diversity and compare it with the performance of the network using traditional omnidirectional antennas.

5.0 Proposal Details

II. Statement of the Problem

The current trend in 802.11b networks is to use omnidirectional antennas in such networks. This is due to the relative simplicity in which these types of antennas can be implemented and deployed in such networks. This simplicity however, imposes some limitations on the performance of such networks. The use of omnidirectional antennas results in lower power efficiency, in the sense that most of the transmitted power is directed towards locations where no network node is located. They also decrease network performance due to co-channel interference from nodes/clients that are transmitting from undesired directions. Proposed solutions to these limitations include the use smart antennas to improve the performance of such networks. One method of implementing these smart antennas is by using switched multiple beam antenna arrays that maximize the power received in desired directions. Most studies done on this implementation are done in simulation. This research aims to produce physical measurements on the actual performance of such networks using switched multi-beam antennas.

III. Objectives

The research aims to design, implement and characterize a fixed multi-beam antenna array for IEEE 802.11b networks. This will serve as a physical testbed for experiments regarding the performance gains of fixed multi-beam switching schemes for IEEE 802.11b networks.

In particular, the objectives are:

- To design and implement a fixed multi-beam antenna array prototype
- To integrate the prototype with a commercial off the shelf IEEE 802.11b compliant access point
- To be able to measure the throughput, coverage, packet error rate, and latency of a network employing the switched beam antenna array prototype and compare it with an access point with standard omni directional antennas

IV. Literature Review

Multi-beam antennas have been extensively used in older types of wireless communication systems. These include satellite communications, radar systems, etc [1,7] and are also being investigated for use in cellular and wireless local area networks (WLAN) [8,10]. There are several ways of implementing such multi-beam networks, which include the Blass and Butler matrix beamformers. Of the two, the butler matrix is of greater interest due to its more compact implementation and its similarity to the Fast Fourier Transform (FFT) [13]. There have been numerous developments regarding the improvement of the RF characteristics of the Butler matrix, shown later, and several researches regarding the use of such multi-beam networks on established communications networks.

A. Multibeam antennas

Multibeam antennas are antenna arrays that employ the use of beamforming networks to produce multiple independent beams for a single antenna array. These network consist of elements that introduce phase shifts and weighting on the waves received by the antenna array in parallel, thereby producing simultaneous beams. Two basic types of multibeamforming networks employed for RF/microwave systems are the Blass matrix and the Butler matrix beamformers [1]. Particularly of interest is the Butler matrix beamformer, due to the large reduction of circuit elements that is required to implement it, as compared to the blass matrix beamformer. The two beamforming networks are analogous to the DFT and FFT in digital signal processing theory.

A.1 Blass beam-forming array

The beamforming network attributed to Blass [12] can be used to produce any number of simultaneous independent beams in different directions. The radiating elements of the array are connected to waveguides/transmission lines that are terminated at the ends by a matched load. These waveguides/transmission lines are tapped in locations where the appropriate phase shift is required and then combined to produce the desired beam. The blass matrix beamformer is illustrated in figure 1 [1].

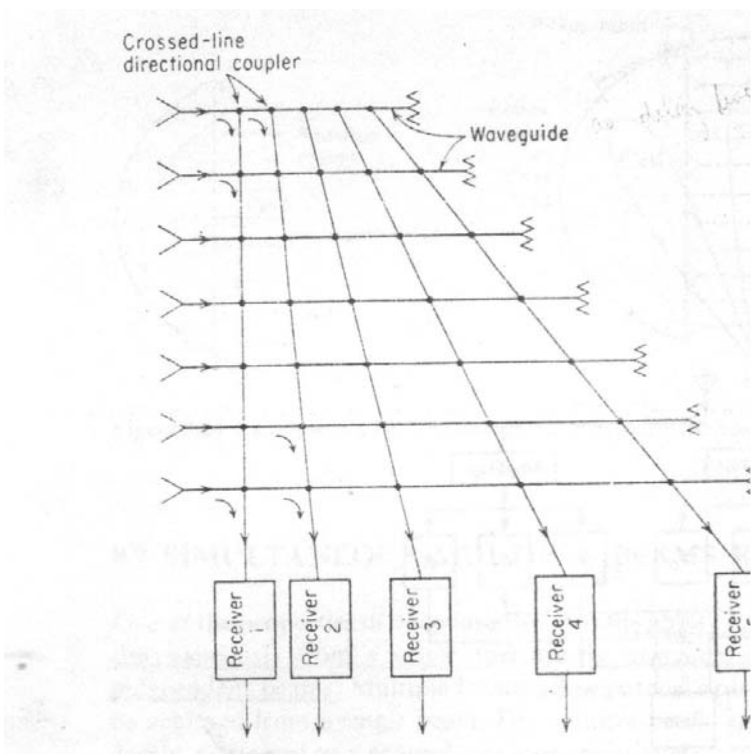

Figure 1. Blass beamformer

It can be seen from the illustration that in order to produce M beams from N radiating elements, it is required to have MxN taps/couplers, N waveguides, radiating elements and matched loads. This type of beamforming network would require a large amount of waveguides and couplers, and would have a very large size.

A.2 Butler matrix

The Butler matrix is a lossless device that employs directional couplers and fixed phase shifters to form N simultaneous independent beams/channels from an N element antenna array, where N is some power of 2[2]. From antenna array theory, the most critical part of the beamforming function is the relative phase shifts of each of the radiating elements. First concern regarding the Butler matrix is the relative phase error with respect to the bandwidth. The overall bandwidth of the matrix is determined by the elements that were used to build it, which are the directional couplers and fixed phase shifters. Since these couplers and phase shifters are usually constructed using transmission line circuits, this implementation of butler matrices usually have fast degrading relative phase errors as the frequency is changed from the design frequency.

There have been several methods that have been presented to improve the bandwidth of the butler matrix. Foti and Macnamara [3] have presented a procedure for designing and implementing wideband butler matrices using schiffman lines as the fixed phase shifters for the matrix. They have experimentally shown that this butler matrix configuration was able to produce a bandwidth of 26%. The drawback with this implementation of the butler matrix is that it would require the implementation of long reference lines, and couplers with very precise even and odd mode characteristic impedances on a relatively thick microstrip substrate, which would mean a very high complexity and difficulty in its implementation.

Another configuration that improves the bandwidth of the butler matrix is by using tandem couplers and phase shifters. There have been several published papers employing this configuration, and were found to produce multi-octave bandwidths. The use of tandem couplers and phase shifters greatly increase the size and complexity of the fabrication of the Butler network.

Hayashi et.al.[4] have proposed another configuration to improve the bandwidth of the relative phase errors of the butler matrix. Their study implemented a 4x4 butler matrix feed network and incorporated half-wavelength open stubs to improve the phase error performance of the butler matrix. They have shown experimentally that their modified butler matrix configuration produced relative phase errors not exceeding 2 degrees over their frequency of operation (850MHz to 900MHz). This is a great improvement over the average phase errors of 11 degrees that was measured experimentally. The advantage of this implementation is the relative simplicity of how it is fabricated in planar configuration.

Another concern regarding the implementation of the butler matrix is its large size and difficult to implement crossovers, especially when trying to implement it for large arrays. For an N element array, it would require $(N/2)\log_2 N$ directional couplers, and $(N/2)\log_2(N-1)$ fixed phase shifters. This is a small problem for small arrays, but large arrays would require a large number of couplers, phase shifters and crossovers which make it difficult to compactly fabricate the circuits, specifically when implemented in microstrip or stripline configuration.

Bona, et. al[5]. have proposed to use suspended strip line in order to make the layout of the butler matrix more compact, and minimizes the difficulty of layouting the crossover sections between couplers. The suspended stripline consists of 2 conducting layers and 3 dielectric layers sandwiched between 2 ground planes. The design requires extensive even and odd mode analysis to find the optimum overlap between the conducting lines to produce the desired coupling for the couplers, and to minimize the coupling for the crossover between the hybrids. This configuration also brings about the problem between interconnections between the 2 conducting layers. This would require vias to be used as interconnects, which also have degrading effects on transmission line circuits. This configuration gives an alternative to single conducting layer transmission line circuits, where the crossovers become a problem in the layout of the circuit, which sometimes make the layout very large. The drawback of this configuration is the increased complexity in the design and fabrication, due to the use of multilayer printed circuit boards with different dielectrics used for the non-conducting layers and the extensive even and odd mode analysis required. This configuration would also be more costly since vias are also to be incorporated in the circuits when interconnecting lines that are not on the same conducting layer.

Shelton and Hsiao[6] have shown that the number of couplers required for the butler matrix can be cut in half if the beams are not required to transmit/receive simultaneously. They have shown that by rearranging the configuration of the couplers and adding compensating phase shifters, it is possible to make the butler matrix symmetric. This allows the removal of one half of the circuit at the line of symmetry and properly terminating at the cut line of symmetry. This gives rise to a reflective butler matrix, which uses only half of the required couplers of the conventional butler matrix. This configuration does not have separate input and output ports, which means that the input and output ports of the butler matrix are shared. This means that it is not possible to transmit/receive from all the beams simultaneously as is. If it is desired to simultaneously transmit/receive, circulators must be added to the ports to separate the incoming and outgoing waves.

A.2.1 The Butler Matrix and the FFT [13, 14]

As earlier said, the Butler matrix beamformer is similar to the Fast Fourier Transform in signal processing. Let us first look at the DFT and its analog in beamforming, which is the blass beamformer. The DFT takes N discrete samples of a signal in the time domain, and transforms it into N samples in the frequency domain. The blass matrix on the other hand, takes N samples in the aperture domain (i.e. the inputs to the N radiating elements), and transforms it into N beams in the beam domain (i.e. the output beam ports of the blass beamformer.). For both cases, N can be any positive integer. There is a more efficient way of computing the DFT of a discrete time signal, and similarly, a more efficient way of transforming from the aperture domain into the beam domain. For the DFT, the computationally efficient way of computing this is by using the fast fourier transform, and analogously for the aperture domain, the more efficient transformation is done by using a butler matrix beamformer. For both cases, N , which is the number of time samples for the FFT and the number of radiating elements for the butler matrix, must be some integral power of 2 ($N = 2^p$).

The number of complex multiplications done in the FFT and DFT are analogous to the number of couplers that are needed to implement the Blass matrix beamformer and the Butler matrix beamformer. Let us consider an 8 x 8 Blass matrix beamformer. This type of beamformer would require $8^2 = 64$ couplers which is analogous to an 8 point discrete fourier transform, which requires $8^2 = 64$ complex multiplications. Now consider an 8 x 8 Butler matrix beamforming network. In order to produce 8 simultaneous independent beams, it is required to have (8/2) log2(8) = 12 couplers, as compared to the 64 required for the Blass beamforming network. Analogously, the FFT performs (8/2) log2(8) = 12 complex multiplications as compared to the 64 complex multiplications required to perform an 8 point DFT. The tree graph representation of the FFT and the block diagram of the butler matrix are shown in the following figures.

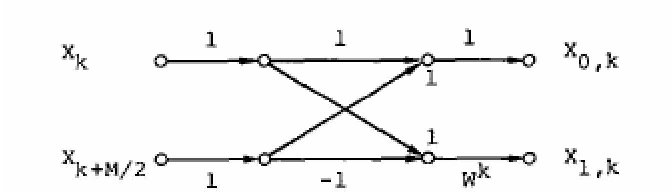

Figure 2. Tree graph of FFT algorithm

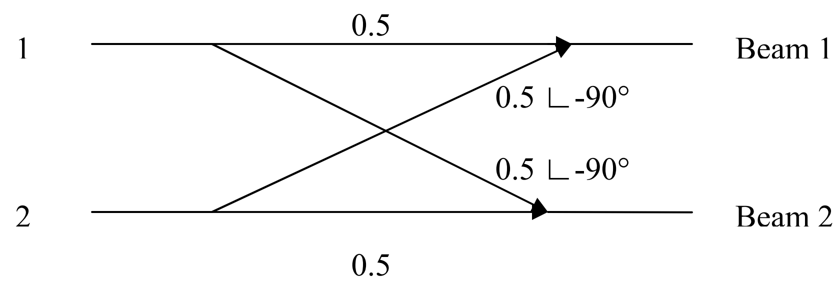

Figure 3. Tree graph of 2x2 Butler matrix

Since the FFT and the butler matrix are similar, it is also possible to perform butler matrix beamforming by performing spatial FFT on the aperture of the antenna to produce the simultaneous independent beams [14].

B. Multibeam Antenna Arrays for Wireless Communications

Multibeam antennas have been considered for use in different communications systems. These include satellite communications, cellular networks, and wireless local area networks.

Yamasa, et. al. [7] have presented a study on feed systems of multibeam antennas that are geared for S-band mobile satellite communications. The paper presents the design of the S-band multibeam feed network that is assumed to be implemented with a 10m diameter reflector. The antenna system is to produce multiple independent simultaneous beams. This allows the antenna system to produce high gains and directivities, and also allows for frequency re-use, similar to the sectoring concept for cellular systems.

Yingjie, et. al.[8], have published experimental results that show the performance gains that are achievable by using multibeam antennas in cellular base station applications, and compared the results to the traditional dual-diversity three sector antenna configurations. Selection combining was used in the multibeam configuration, where the two beams with the strongest received power were switched to the receiver system. The arrays that they used for the evaluation of the performance of multibeam arrays were 12 beam and 24 beam antenna arrays. The tests were performed in typical cellular base station locations that were located in heavy and light urban environments, and were done in the receive path of the base station. The figure below shows their results. Figure 4 shows the relative gain of the switched beam antennas over the dual diversity sectorized antenna of the base station for light (Bellevue) and heavy (Seattle) traffic. This shows that the switched beam antenna produces an average of about 5dB gain over the conventional dual diversity sectorized antenna. This 5dB gain improvement would in effect allow the base station using switched beam antennas to have farther range, and increased SNR over the conventional base station antenna. The researchers also investigated the effect of the switching time and hysterisis level of the switched beam antenna on the gain of the antenna. Figure 5 shows the effect of the switching time of the SBA on the gain relative to a 0.5S switching time..

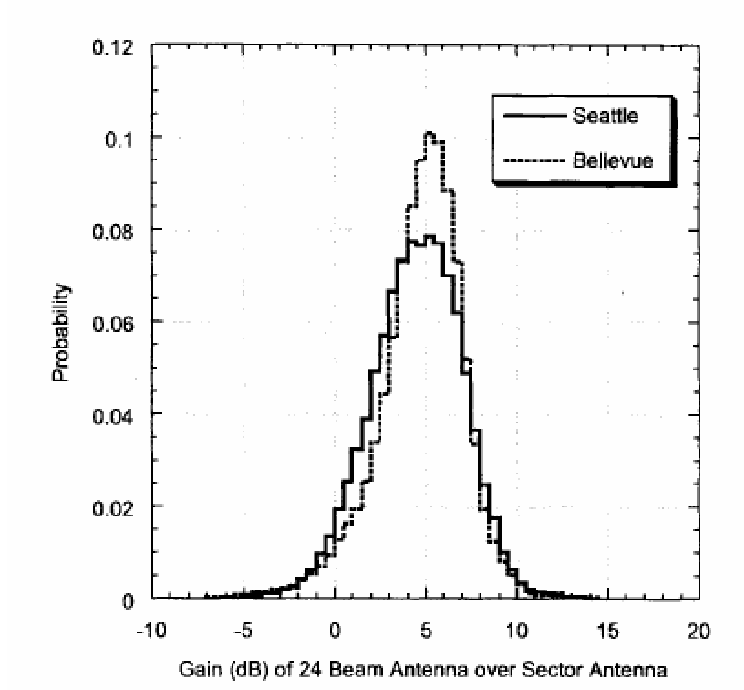

Figure 4. Histogram of gain of 24-beam antenna over dual diversity sectorized antenna

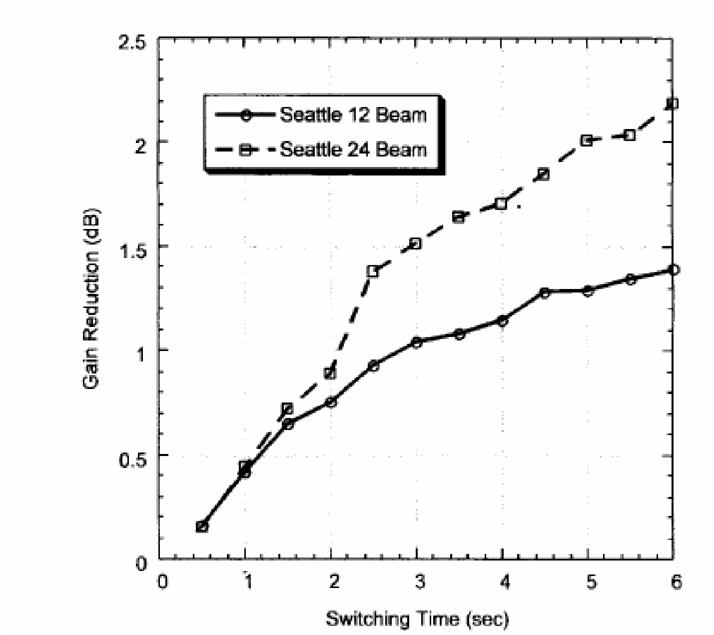

Figure 5. Gain reduction vs Switching time relative to 0.5 S switching time and 0dB hysterisis level case

Denidni and Libar [9] also investigated a microstrip planar feed network for a switched beam antenna array for PCS applications. In this paper, they developed an antenna array and an 8x8 butler matrix for operation at 1.9GHz for PCS applications. Their study included the design and implementation of a microstrip butler matrix and the performance of the beamforming network by comparing the results with the prototype with simulated results that were done using matlab. The paper emphasized more on the RF characteristics of the beamforming network for the PCS band. It does not include the testing of the performance of the beamforming network when implemented on an actual PCS network.

The paper done by Caldwell, Kenney, and Ingram[10] investigates the application of a switched beam antenna system on an 802.11b network. Their paper presents the design and implementation of a switched beam smart antenna for an 802.11b wireless access point. Their proposed system uses an 8x8 Butler matrix as the beamforming network for the antenna array. All the circuits required for the implementation of the butler matrix, which includes the directional couplers and phase shifters, were fabricated in microstrip transmission lines. The motivation for this choice in implementation of the butler matrix is due to the low cost that is associated with its fabrication. The trade-off with this choice in fabrication medium is that the system would have a relatively narrow bandwidth, and larger size. The researchers opted to use meandering lines for the phase shifters to somehow alleviate the increase in size associated with the use of microstrip transmission lines as the fixed phase shifter elements.

The butler matrix is to cover a 90 degree sector of the coverage area. This implies that in order to cover an entire 360 degree area, 4 of these butler matrices will be required. Since the outer beams (beams near endfire) generated by the butler matrix exhibit scalloping, the researchers opted to omit these 2 beams for the receiver. This means that the ports that correspond to the near endfire beams are properly terminated, and are not available for the receiver to tap into. Their system in effect only has 6 beams from which the receiver or access point can choose from, even though the butler matrix beamforming network actually produces 8 independent beams.

The losses and phase errors of the butler matrix were measured using a vector network analyzer. Using these measured results, the array factors of each of the ports were calculated and using pattern multiplication with the unit element pattern, the theoretical beam patterns of each of the independent beams are also calculated. The researchers in effect assume the theoretical pattern results to hold, and therefore neglect the effects brought in by the antenna array itself, which include mutual coupling and other parasitic effects of the array, which can distort the element patterns of each of the antennas used for the array. If the coupling between elements are significant and element patterns of the array are distorted, the pattern multiplication that was used to compute the radiation pattern of the beamformer and antenna array would be invalid.

The beamforming network presented in the paper also includes a switch matrix that handles or decides which beams are routed to the wireless access point. The switch matrix itself is also implemented in microstrip configuration again due to its small cost, and ease of tuning by using open or short circuited stubs if further matching is required. The switching matrix also includes a microcontroller unit that serves as the "brains" of the switching operation.

The operation of the switching matrix/network is as follows: 6 outputs of the butler matrix are connected to 10 dB couplers, which couple 10 percent of the power of the signals that are outputted by the butler matrix. This small amount of power coupled by the 10 dB couplers are then inputted to RF power detectors which measure the amount of power in each of the output ports of the butler matrix, which correspond to the amount of power or the signal strength received by each of the beams of the butler matrix. The outputs of the RF power detectors are then connected to serial analog-to-digital converters of the microcontroller, and are polled sequentially by the MCU. After polling, the microcontroller selects the two beams that have the largest signal strength and then sends control voltages to the corresponding RF switches of these two beams, and directly connects it to the access point. The other switches that correspond to the beams with lower received signal strength are then connected to ground. This choice of connecting the outputs of the unused channels to ground may bring about some concerns. By terminating the unused outputs with a ground, the power that in these ports are not absorbed, but are reflected back into the previous stages of the network. These reflected waves may interfere with the signals in the other channels, and may in effect increase or decrease the measured power that is received in the other ports. I believe that it would be better if the unused outputs were terminated by matched loads, so that the signals in the unused beams are dissipated or absorbed completely by the matched load terminations so that no reflections would occur, and possibly eliminate or minimize the interference caused by the reflected waves.

The effect of the beamforming network on the wireless network itself was only analyzed theoretically. The researchers of this paper used the formula below[11] to approximate the increase in SNR that would be brought about by the beamforming network, where M is the number of antenna elements, and σ is the standard deviation of the angle of arrival of the incoming waves.

$$\Delta SNR = \frac{M\left(1-e^{-\frac{\sqrt{2}}{\sigma}\left(\frac{\pi}{M}\right)}\right)}{1-e^{-\frac{\sqrt{2}}{\sigma}(\pi)}} \qquad (1)$$

It was stated in the paper that, including the losses contributed by the butler matrix and switch matrix, the approximate increase in SNR brought about by the beamforming network is 8.5 dB, while the ideal case of having lossless butler matrix and switching matrix would provide an SNR increase of 14 dB. It was also stated that this increase in SNR would bring about magnitudes of improvement on the bit error rate of the network. The paper did not include measurements of the implemented beamforming network connected to an actual wireless local area network.

Ramathan, et. al. [15] conducted a study on the effects of using directional antennas on 802.11 networks and compared its performance with omnidirectional antennas that are usually used with 802.11 clients. The research was done as simulations on 802.11 networks that were operated in ad-hoc mode. Their simulation results show that throughput of the network can be increased by as much as a factor of 10 when directional antennas are used by the wireless clients. Figure 6 shows the comparison between the throughput of the network when omnidirectional antennas and directional antennas are used, as a function of the density of the network.

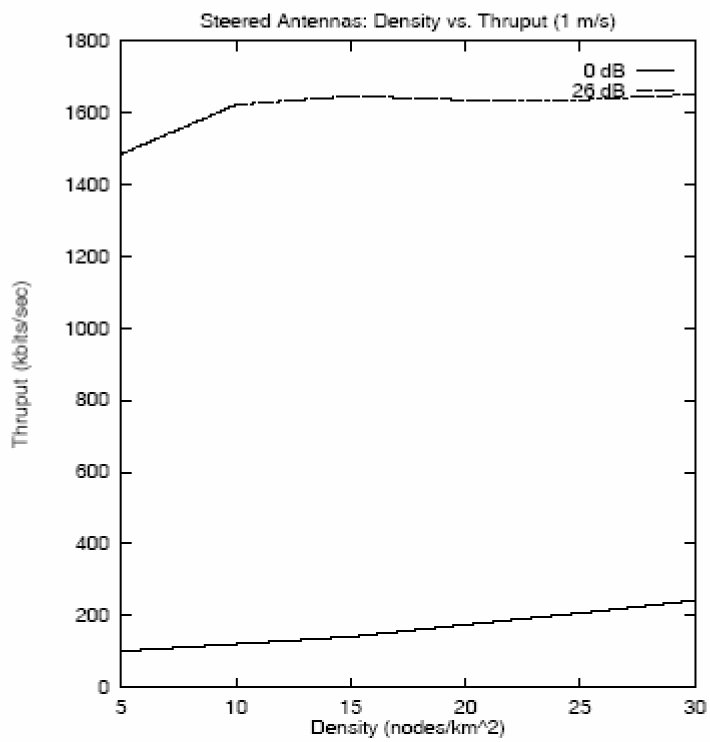

Figure 6. Throughput as a function of network density

Results for this research also showed the performance difference between using switched beam directional antennas and continuous beam steering antennas. Figure 7 shows their simulation results on how the gain of switched beam and steered beam directional antennas affect the throughput of the simulated network. Their simulations for the switched beam antennas increase the gain, but do not change the number of radiating elements of the antenna. This means that by increasing the gain of the switched beam antenna, they make the beam narrower, but since the number of elements is not increased, the number of beams that the switched beam has is still the same. This means that some parts of the coverage area will have antenna gains that are smaller than the gain of the omnidirectional case, which would account for the decrease in throughput for antenna gains above 10dBi. If the number of elements of the switched beam antennas were increased along with the gain, the coverage area of the switched beam case would not or at least be minimally affected which might still provide some gains in the throughput of the network for gains larger than 10dBi.

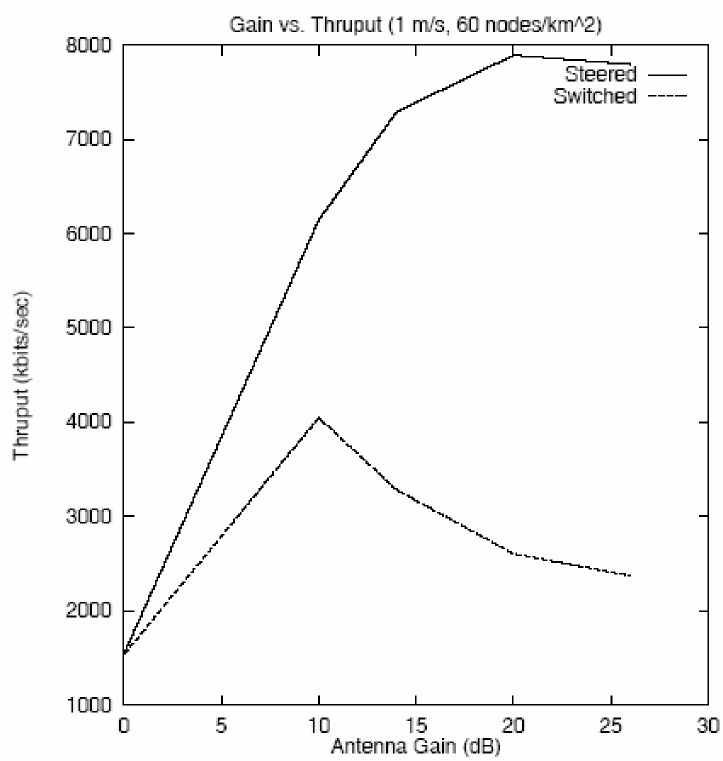

Figure 7. Throughput as a function of antenna gain.

The researchers conducted a field test in order to verify the simulation results that they have acquired, and results were said to be "remarkably close to simulation results", though no actual measured data were shown in their paper.

Dham [16] conducted research on the use of directional antennas and directional MAC on wireless LAN networks. The simulations assumed that the channel was line of sight, and that there is no multipath present. Several scenarios were used for the MAC protocols:

Scenario A: Omnidirectional antennas for all packets

Scenario B: Directional antennas used for Request to Send (RTS), Data, and Acknowledgement (ACK) packets, and omnidirectional antennas for Clear to Send (CTS) packets

Scenaro C: Directional antennas used for transmitting RTS, Data, CTS and ACK packets

Scenario D: Data is transmitted by directing the transmitter antenna towards the receiver while the receiver uses omnidirectional antennas.

Figure 8 shows the throughput of the 4 scenarios with time. Scenario C produced the highest throughput, while Scenario A, which is what is commonly used for wireless LANs, produced the slowest throughput. The results show that the use of directional antennas provides gains in the throughput of the network, in simulations at the very least.

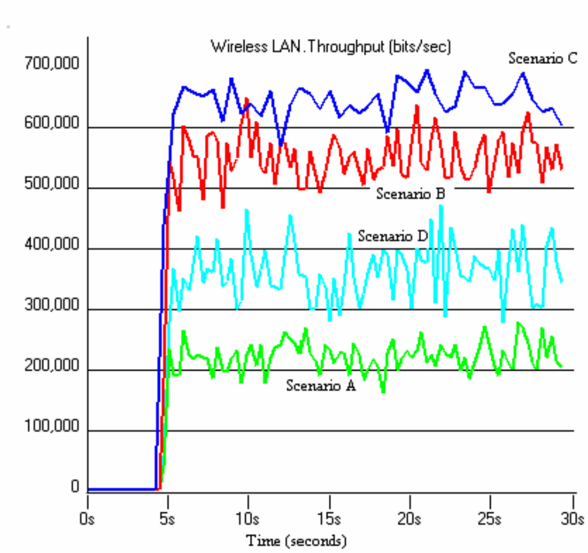

Figure 8. Throuhput vs Time

Summary

As seen from most of the papers shown here, there is very little testing of multiple beamforming networks on actual wireless networks. Most results talk about theoretical improvements that may be brought about by the use of multibeamformer networks on these wireless networks, or mostly talk on the RF characteristics of the implemented beamforming network.

V. Proposed Methodology

The development of the project involves the follwoing stages:

1) Design and implementation of the antenna array
2) Design and implementation of butler matrix
3) Design and implementation of the switching matrix
4) Integration of individual system blocks
5) Testing and characterization of the beamformer testbed in an 802.11b network

A. Antenna Array

The antenna array will consist of 4 radiating elements spaced at 1/2 wavelength apart at the carrier frequency and will be arranged in a linear form. The antenna elements will be spaced at d=lambda/2=c/f=6.25cm apart. This half-wave spacing ensures that the array will have the largest gain and directivity that does not have grating lobes.

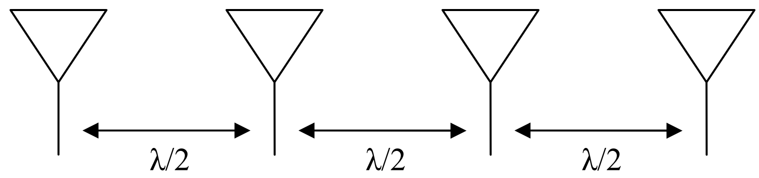

Figure 9. Antenna array geometry

The radiating elements to be used will be the SF2450 dielectric chip antenna manufactured by Furukawa electronics. The SF2450 antenna is designed to operate at the 2.4GHz frequency band, and is aimed for 802.11b and Bluetooth applications. The SF2450 antenna has the following dimensions 8.8x2.9x0.7mm. The very small size of the SF2450 antenna ensures that the radiating elements will spaced relatively far away from each other at lambda/2 such that the adjacent antenna elements do not significantly affect the unit patterns of each antenna element. These assumptions allow us to theoretically compute the radiation pattern of the 4 element SF2450 array by simple pattern multiplication of the array factor for a 4 element antenna array spaced lambda/2 and the unit element pattern of the SF2450.

The SF2450 antenna has 2 feeding methods specified in its data sheet. These are the Mono-pole and Inverted F feeding methods. The 2 feeding methods are illustrated below:

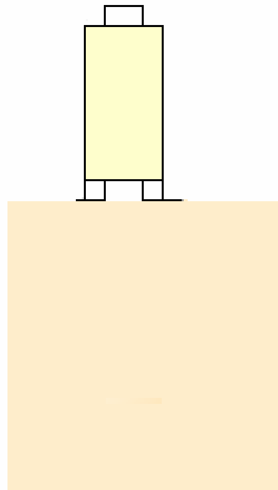

Figure 10. Mono-pole feeding

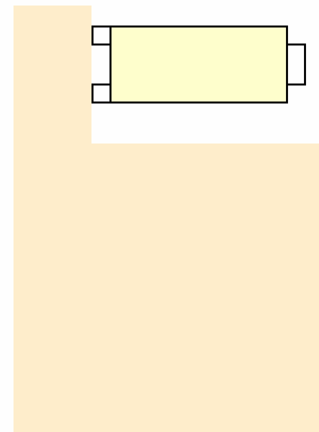

Figure 11. Inverted F feeding

For both feeding methods, the critical design parameter that significantly affects the performance of the antenna is the antenna position and ground plane of the substrate/pcb to which the SF2450 is to be mounted. The data sheet shows the variations of the performance of the antenna for different mounting conditions. These include the distance of the antenna from the ground plane, and the size of the ground plane itself. It must be noted that the information provided by the data sheet is only applicable for the type of substrate/pcb that they used in the testing, and may no longer hold when other types of substrates/pcbs are used. This means that the optimum dimensions for the ground plane needs to be determined before the fabriction of the array. This requires prototype antennas to be fabricated and tweaked to be able to find the optimum configuration for this project. Testing will be done using a vector network analyzer to measure VSWR, input impedance, and bandwidth of the antenna.

B. Butler Matrix

The 4x4 Butler matrix requires 4 90degree 3dB couplers and 2 phase shifters. The configuration of the butler matrix beamformer is shown below:

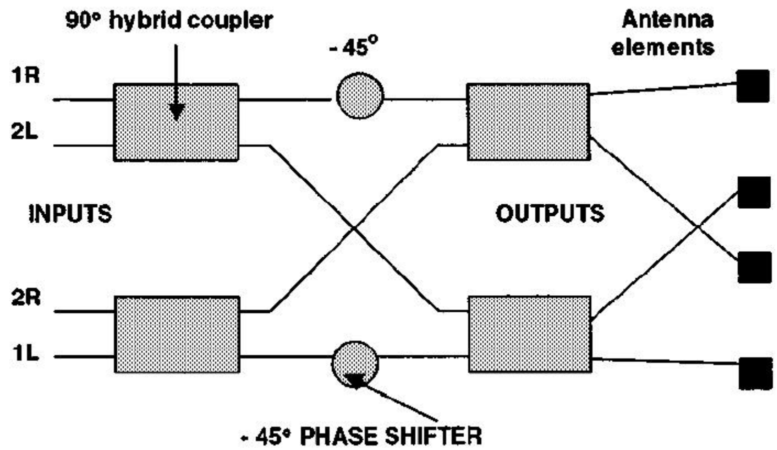

Figure 12. 4x4 Butler Matrix

There are 2 ways in which the buttler matrix may be impelemented. The first being the fabrication of the hybrid couplers and phase shifters in microstrip form and the second would be to use commercial off-the-shelf couplers. The use of COTS couplers does away with the designing of the couplers, but also removes the possibilty of tweaking of the coupler, if the need arises.

B.1 Microstrip 3dB 90degree coupler

The design of the coupler for a specified frequency is straight forward. The branch line coupler requires 4 quarter-wavelength transmission lines connected in a square, as shown below. The design equations for the impedances of the series and shunt lines for specified values of coupling are shown below:

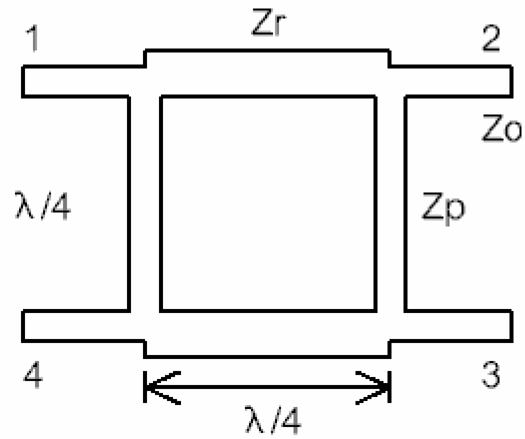

Figure 13. 90 degree Branch line coupler

$$\frac{1}{Zr^2} + 1 = \frac{1}{Zp^2} \tag{2}$$

$$C = -20\log_{10}\left(\frac{\frac{1}{Zp}}{\sqrt{1 + \frac{1}{Zp^2}}}\right) \tag{3}$$

For the required 3dB coupling, the normalized admittances of the series and shunt lines are 1 and 1.414 respectively. For a 50 ohm system, the impedances of the lines are 50ohms and 35.36 ohms respectively. For the synthesis of the actual transmission line dimensions, the software tool, txline, which is a transmission line calculator by advanced wave research and bundled with the microwave office suite, will be used to calculate the actual dimensions of the transmission lines. Preliminary designs of the branch line coupler will be simulated using microwave office suite before it is fabricated. This allows us to first verify the design at software level before actual fabrication is done. This allows the coupler to be tuned such that it satisfies the phase and amplitude balance requirements before it is actually fabricated. This takes in to account the effects of the discontinuities in the microstrip circuit which are not accounted for in the design equations.

B.2 Phase shifters

The phase shifters will be implemented using transmission lines whos lengths introduce the required phase shift. AS with the coupler, the phase shifter will be implemented in microstrip transmission line form. The phase shift ϕ associated to a transmission line of length *l* is given by the equation:

$$\phi = \frac{2\pi}{\lambda_g} l \qquad (4)$$

where *l* is in meters, ϕ is in radians and λ_g is one wavelength in the transmission line medium. For microstrip transmission lines, the wavelength is given by $\lambda o/\mathrm{sqrt}(\varepsilon_{effective})$, where λo is the wavelength at free space, and $\varepsilon_{effective}$ is the effective dielectric constant of the microstrip substrate and free space.

C. Integration of Butler matrix

Since there are 2 ways in which the 90 degree couplers may be implemented, there will be 2 implementations of the butler matrix as well. For the microstrip couplers, the couplers and phase shifters will be implemented in microstrip transmission line form on a single substrate/pcb. This provides seamless interconnection between the couplers and the phase shifters, since both components are implemented in the same form. If COTS couplers are to be used, the couplers will be mounted on the same substrate/PCB as the phase shifters and interconnects to the other stages. The couplers will have to be soldered onto the PCB, which may introduce undesired effects to the performance of the circuit due to the discontinuities associated with the soldering of the components.

Testing of the butler matrix will be done using a vector network analyzer. The scattering parameters will be measured. Measurement of the butler matrix is as follows. The network analyzer is connected to a pair of ports of the butler matrix, while the other ports not connected to the network analyzer are terminated by matched loads. The S-parameters for each pair of ports are measured, and the Scattering parameters of the butler matrix, which is an 8x8 matrix, can be inferred from these measurements. Critical parameters of the butler matrix are the transmission coefficients from the input ports to the output ports, which should all be equal, and the phase shifts between each ports, which is critical for the beamforming operation of the butler matrix.

D. Switch matrix

The switch matrix is the stage of the testbed that will route the beam with the highest received power to the 802.11b access point. The switch matrix has the following blocks; RF switches, directional couplers, RF power detectors, and a microcontroller. The 4 inputs of the switch matrix, which corresponds to the 4 outputs of the butler matrix, is connected to 4 10dB directional couplers, where the through ports are connected to a single pole single throw RF switch each. The output of these switches is the output of the switch matrix. The coupled ports of the couplers will be used to measure the received signal strength of each of the beams of the testbed. The coupled ports will be connected to another RF switch whose output is connected to an RF power detector. The output of the power detector is connected to the microcontroller. The microcontroller polls the output of the 4 coupled ports and does this by changing which coupler is routed to the RF detector by controlling the SP4T RF switch. The microcontroller then samples the output of the RF detector for each beam and stores these values. It then compares these values and then picks which ports have the largest powers. There will be 2 possible ways in which the microcontroller can pick which beams will be connected to the access point. The microcontroller may switch only the port with the highest received signal power to the access point. Another switching scheme would be that the microcontroller switches the 2 or 3 ports with the largest received power, and inputs these ports to a power combiner. The power combiner then inputs the summed signal into the access point. In this case, the beams with the smallest received powers will not be connected to the access point. An illustration of the configuration of the switch matrix is shown below.

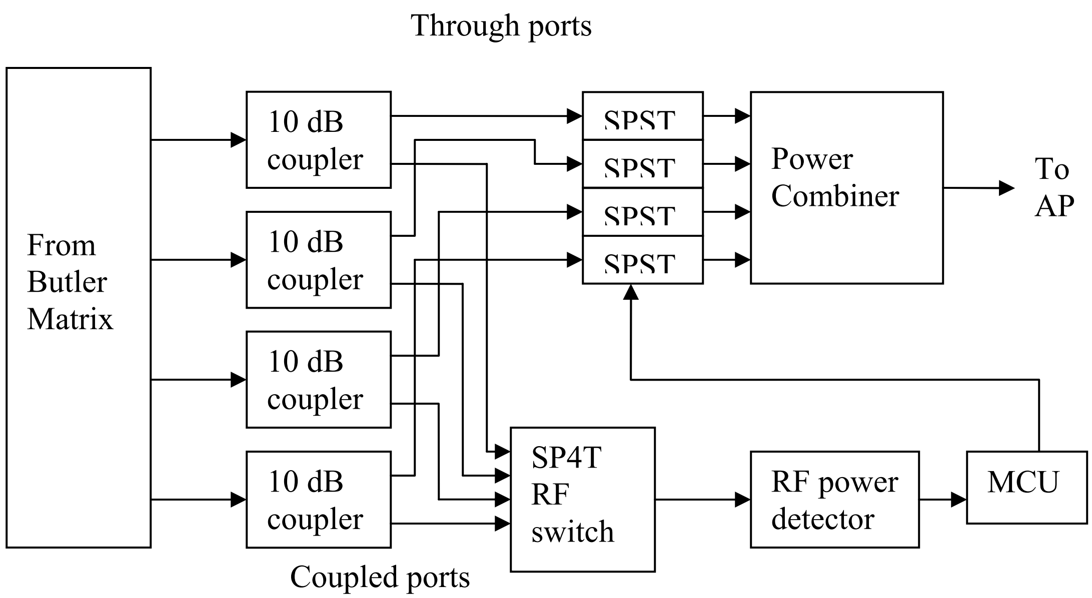

Figure 14. Switch Matrix

E. Integration

The ports of the antenna array are connected to the input ports of the butler matrix. This may be done by using male and female SMA connectors to directly connect the 2 blocks, or by using coaxial cables. The 4 output ports of the butler matrix are then connected to the inputs of the switch matrix, which are 10dB couplers. The RF output of the switch matrix is then connected to the access point. It is possible to add amplifiers in the circuits to null out the losses of the butler matrix and switch matrix. An illustration of the integrated system is shown below.

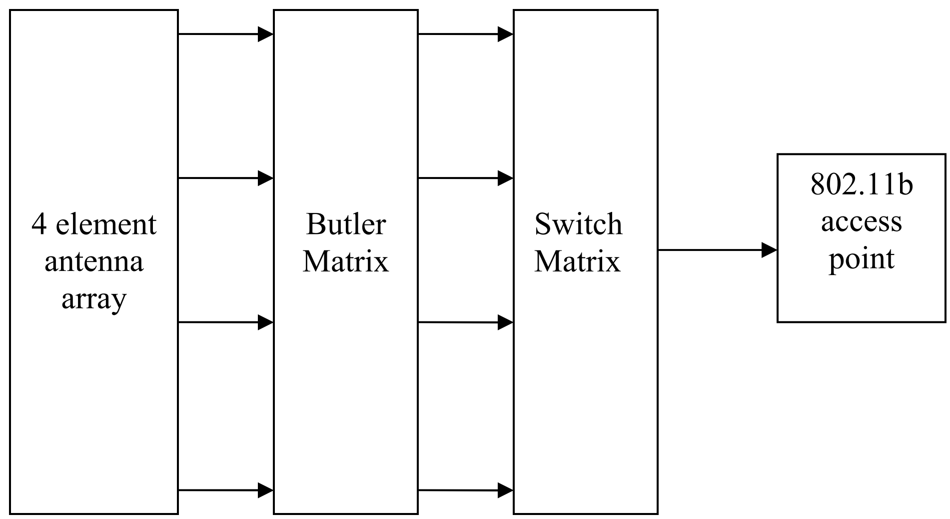

Figure 15. System Block Diagram

F. Testing and characterization of the beamformer Testbed in an 802.11b network

Once the switched multibeamformer prototype has been integrated, the performance of an IEEE 802.11 network employing this prototype will be tested. Software tools will be used to evaluate the throughput, latency, received signal strength, and packet error rate of the network. The prototype will be used only during the receive mode of the wireless access point, while an omnidriectional antenna will be used during transmit mode. In effect, the access point transmits omnidirectionally, while receives directionally. Testing will be done in DEEE 306. The evaluation of the network will be done for single user and for multiple user networks.

F.1 Software tools

The software tools that may be used for the evaluation of the network are the following:

- Ixiacom's Qcheck
- Wildpacket's Airopeek

Qcheck

Qcheck is a free network diagnostic tool distributed by ixiacom. Qcheck is able to measure the throughput, response time, and a streaming test that returns the packet loss of the network. One network node will act as the console for the application, which is where all data measured by Qcheck is displayed, while a network endpoint program or qcheck must be installed in the other node where tests will be performed. Since this tool is for use with general networks (not necessarily WLAN), it is not able to measure signal strength.

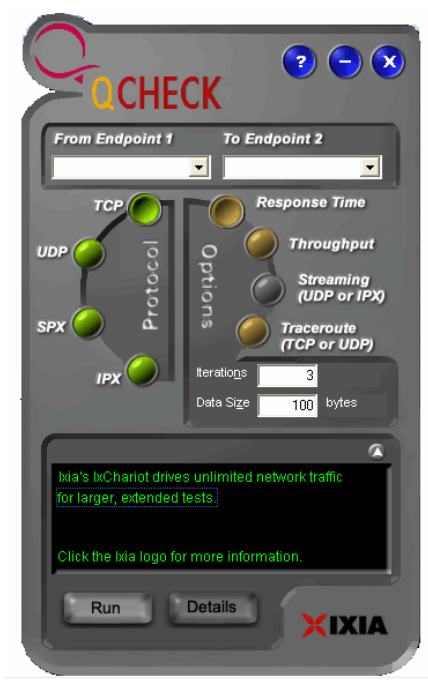

Figure 16. Qcheck console

Airopeek

Airopeek is a proprietary wlan packet analyzer that is distributed by wildpackets. It is able to display data rate, channel, and signal strength for each packet on the WLAN network. Being a proprietary software package, it is more complete than Qcheck which is freeware. Wildpackets also provide a demo version of airopeek, which limits the number of packets and the amount of time in which the network can be monitored, though there is no limit as to the number of times that the program can be used.

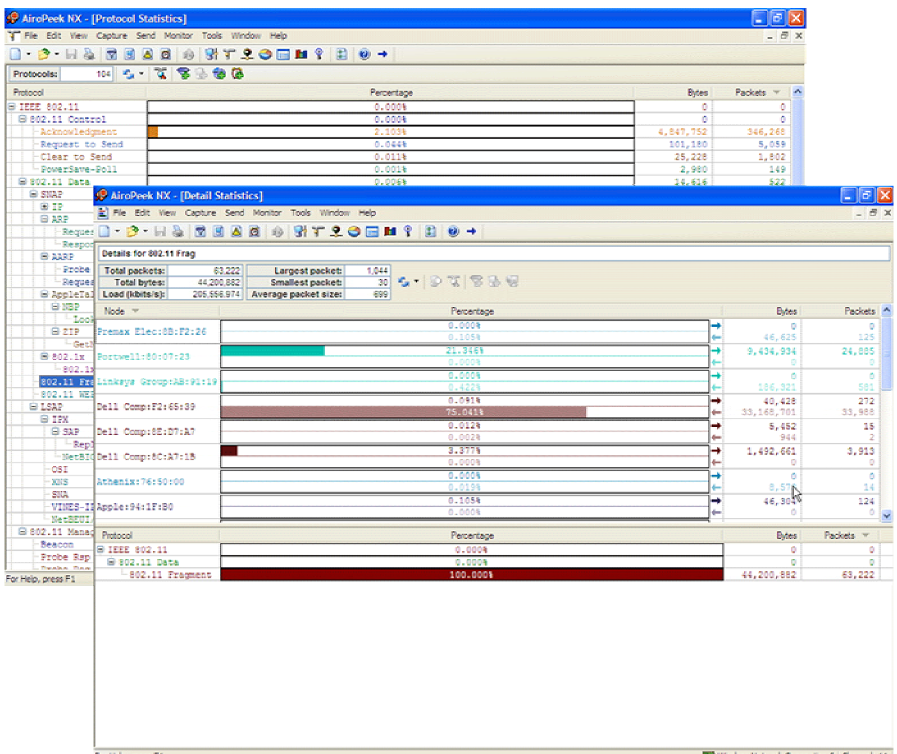

Figure 17. Airopeek

F. 2. Test setup

Several test set ups will be done for the testing of the network. There will be tests done for a single user network, and for multi-user networks. One network node will be connected to the access point through Ethernet cables. This node will serve as the console/server for the software tools where data on the network will be stored/collected. The other nodes in the network will be wirelessly connected to the small network through the access point. The network will be run in infrastructure mode, where data in the wireless network must pass through the access point first. Several setups, where the number of wireless nodes in the network will be varied, will be done.

F.2.1 Single User Setup

The single user test setup requires 2 nodes in the network: 1 connected wirelessly, and another wire connected to the access point. Tests will be done with the prototype array, and with an omnidirectional antenna. Traffic in the network will be simulated by the software tools, as well as the measurement of the network performance (PER, throughput, latency, etc.). Tests will be run with the wireless node in different positions relative to the AP, varying the azimuthal angle and distance of the wireless node with the AP.

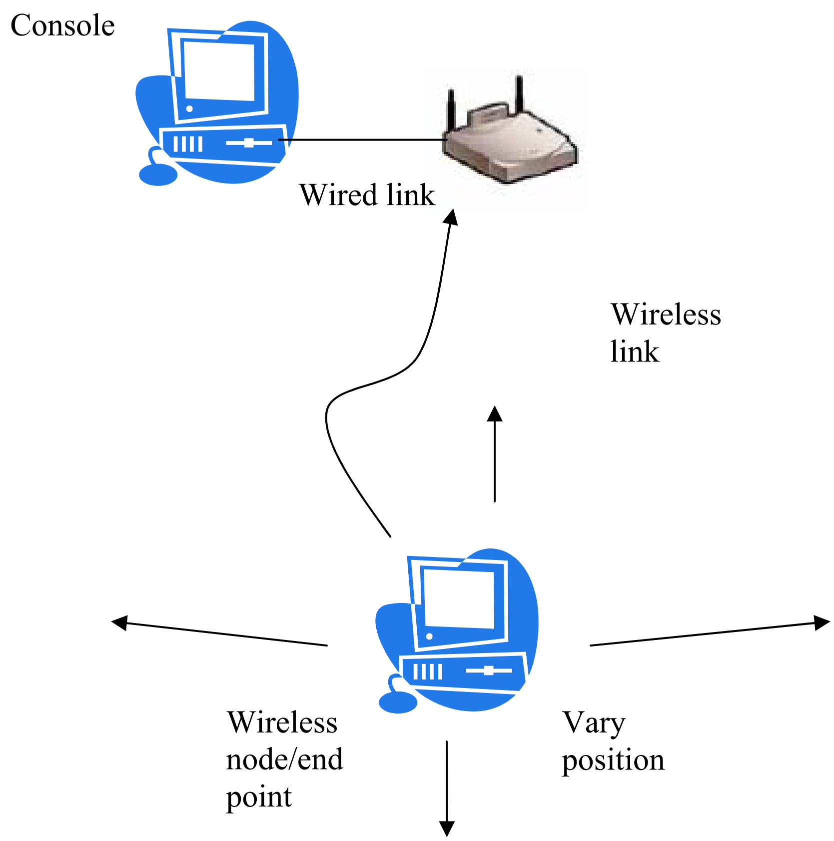

Figure 18. Single User with server connected through wire to access point

Another approach would be to have both the console and the node/endpoint be connected wirelessly to the network. The console node will be in a fixed position relative to the access point, while the network endpoints location will be varied relative to the AP.

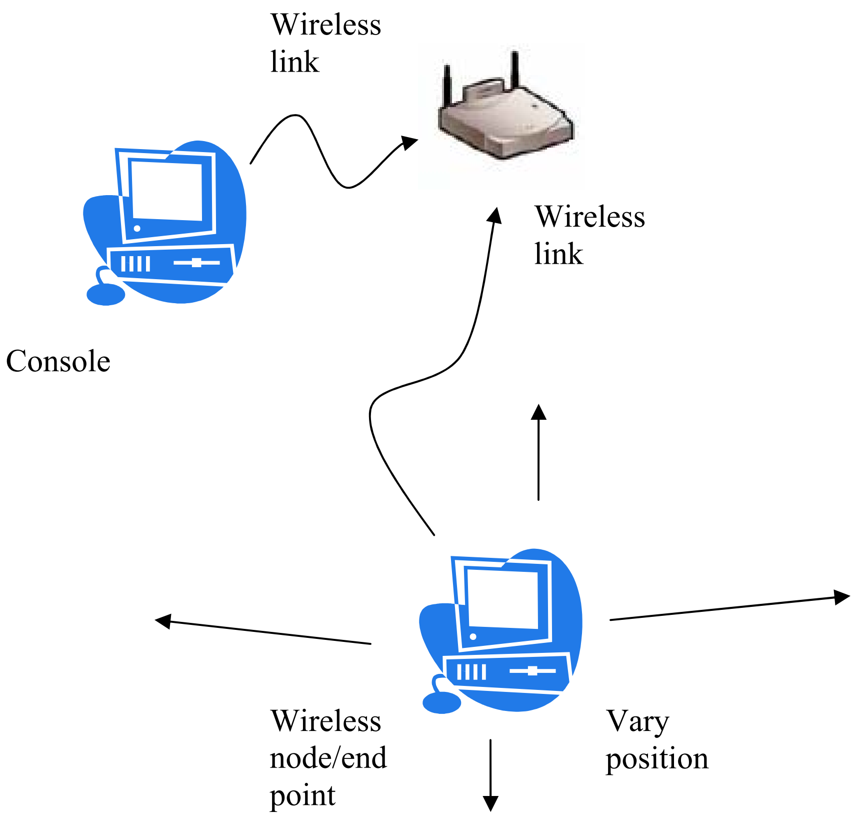

Figure 19. Console node wirelessly connected to network

F.2.2 Multi-User Setup

The setup for the multi-user case will be the same, the only difference is that more wireless nodes will be added to the network. Data gathering will be the same, where all data will be stored and gathered in the console node. Data will be gathered with one node trying to transmit, and multiple nodes trying to transmit at the same time. Locations of the wireless endpoints/nodes will also be varied relative to the access point and each other to gage the performance with nodes close to each other and far from each other.

G. Schedule

The schedule of for the research is shown in figure 20.

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<tr><th colspan="4">NOV-04</th><th colspan="4">DEC-04</th><th colspan="4">JAN-05</th><th colspan="4">FEB-05</th><th colspan="4">MAR-05</th><th colspan="4">APR-05</th><th colspan="4">MAY-05</th></tr>
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</table>

1. Procurement of components
2. Implementation of the 4 element array
3. Implementation of the butler matrix
4. Implementation of the switch matrix
5. Integration
6. Testing and characterization of testbed
7. Documentation and analysis of results

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