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MODULO AND GRID BASED CHANNEL SELECTION IN AD HOC NETWORKS

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Abstract

In this paper, we describe several approaches to spatial-reuse in ad-hoc networks using multiple channels. We analyse many techniques requiring only information available locally and those that do not collaborate with neighbouring nodes. Our justification for this is to avoid extra network overhead. The results we obtain show that intelligent allocation of channels can make a significant performance improvement over that of simply using all available. We propose several approaches to allocating the channels intelligently and a grid-based approach that only requires Global Positioning information.

Keywords

Ad-hoc networks, performance analysis, multi-channel, multi-radio, channel allocation.

1. INTRODUCTION

Ad-hoc wireless networks provide a means of networking together groups of computing devices without the need for any existing infrastructure. Devices (nodes) automatically form a network when within range of another and act as a router by forwarding any packets for other nodes. This permits nodes to communicate further than their transmit power allows and provides more optimal special use of the radio spectrum.

A commonly cited problem with wireless networks is that their capacity diminishes to zero with an increase in the number of nodes. However, the assumption made is that there is no locality of traffic, which we believe is not probable in a larger scale ad-hoc network. However, despite this, the capacity of the network is low due to interference from nodes outside of the communication range preventing transmission.

This paper will look at the capacity of wireless networks with one channel and then expand upon this by developing a number of approaches to increase capacity. We will look at the problem of spatial reuse and whether it can be solved through simplistic channel allocation. Ultimately, one does not wish to impose more overhead on the network, so only approaches where local decisions can be made that provide a global benefit are researched.

2. LITERATURE REVIEW

It was shown by Gupta in [1] that the capacity of a wireless network under a Protocol Model of interference could provide a per node throughput of $\frac{C'}{\sqrt{N \log N}}$ bits/sec. This reason is that even nodes outside of a node's transmission radius can prevent

a node from transmitting by causing an unfavourable signal to noise ratio. The other reason is that traffic in such a scenario is expected to be random and not localised; however, in a large-scale deployment of such a network, locality would be a key factor resolving this issue. Therefore, we concentrate on interference avoidance and methods to increase capacity.

The several general classes to solutions this problem are usually antenna, frequency and MAC based. Antenna techniques attempt to reduce the interference or mitigate it by for example, directional antennas. Frequency-based approaches attempt to increase the capacity by using multiple channels. MAC based approaches attempt to handle the interference and maximise channel usage in the presence of it.

Zhu et al. [2] suggested a MAC-based method to adapt the sensing threshold to the prevailing conditions. They also propose a distributed approach to more accurately predict this threshold that gives a throughput of 90% of the theoretical maximum in a 90-node chain topology.

Directional antenna MAC protocols[3] use switched beam or adaptive antenna arrays to focus the radiated power in a particular direction. This allows two communications to take place without interference where they do not lie on the same axis. Directional antennas provide good spatial reuse and increased radiated power allowing 1-hop communication with nodes further away. However, they can cause a deafness problem[4] because although a node maybe in communication with another, the other nodes nearby will not be aware of this and may repeatedly send RTSs, thereby causing interference.

Finally, multiple channel techniques fall broadly into two categories, single-radio and multiple-radio. Multiple radio algorithms[5] are able to transmit and receive on multiple channels at once, but require extra equipment on the node. When there is just one radio[6], a node may switch between channels to utilise more than one, however, while it is doing this, it may not hear attempts to communicate on a channel which it is not listening on. In addition to this problem, there is a switching delay imposed on the algorithm by the networks card that requires a fixed period of time to complete switching between channels.

3. APPROACHES

We now propose to maximise spatial re-use in an ad-hoc network by utilising multiple channels. Information required for each of the techniques require only information that is available locally, with the most simple of these being the random method that requires no information at all. The set of methods based on modulo only require knowledge of the channel which the data was received on, and in some of the latter approaches, the angle from which the data was received, and the angle at which it is being transmitted. The grid approach only requires information on the current location of the node, which along with the angle can be obtained from a Global Positioning System receiver.

Throughout our work, we assume there is no constraint on the amount of channels that we may use. Whilst the IEEE 802.11 standard places a limit on the number of channels available, we present these techniques as standard-independent and able to work with any wireless technology.

3.1 Random and Incremental

The most basic of multiple channel approaches is making a random choice, in where upon receiving a packet a node retransmits it on a channel chosen randomly from those available. We use this as our benchmark for comparison and for determining whether any improvement has been made. The other approach we use is called incremental whereby a node simply makes use of all the channels by transmitting each outgoing packet on the next channel.

3.2 Modulo

A node forwarding a packet prevents the previous sending node from transmitting thereby limiting the data rate after one hop. Therefore, we initially make a simple modification to utilise the extra channels to mitigate this. On receiving data on channel k , a node forwarding the packet will transmit it on channel $k+1$. Where $k+1$ is larger than the number of channels, the cycle starts again and channel zero is used. The channel in use at hop n , given a starting channel k , and c channels, is defined in equation 1 below:

$$f_n = (n + k) \bmod c \quad (1)$$

Where a transmission is originating from a node, a random starting channel, k , is chosen to avoid the possibility of several adjacent nodes all starting on channel one. This is true for all of the modulo approaches proposed in this paper.

We measured the throughput of a network with a simple chain topology and a constant bit-rate of traffic from the first to last node. Varying the number of channels we find that using this algorithm with five channels provides throughput equal to a one-hop scenario. Therefore, we say the interference range has effect up to approximately five times the transmission radius and therefore at least five channels would be an appropriate choice. However, typical ad-hoc networks are not chain-topologies but we have used this example to establish the minimum number of channels required to eliminate this cause of interference. The modulo approach suffers when the nodes are not in a chain topology because it will experience interference from intersecting and adjacent traffic flows.

3.3 Directional modulo

An better approach, NS EW modulo, is one that minimises the possibility of intersecting traffic patterns interfering.. We propose using a set of channels for traffic travelling north and south, and another set for traffic travelling east and west (Figure 1). When traffic is travelling north the channel is incremented within the NS set, and when it is travelling south it is decremented. This is the same for the EW set, incrementing for east and decrementing for west. Traffic may change from one set of channels to another when the traffic routes in a different direction, and where this is the case, a random channel is chosen from the new set as a starting channel. Traffic travelling east will no longer interfere with traffic on a perpendicular bisect travelling north or south. This approach therefore provides forwarding interference immunity and limited locality interference immunity.

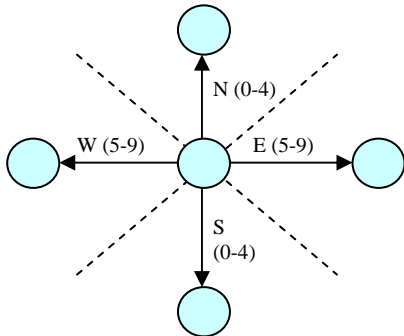


Figure 1: NS-EW channel allocation

0,0	1	2	1	2	1	500,0
	3	4	3	4	3	
	1	2	1	2	1	
	3	4	3	4	3	
0,500	1	2	1	2	1	500,500

Figure 2: Grid-based allocation 2x2 (4)

This approach is somewhat similar to a directional-antenna approach without the need for directional hardware. However, it also provides the forwarding interference reduction that directional approaches do not. Expanding on this technique further, we also test N E S W modulo, whereby a different set of five channels is allocated to each of the four directions on the compass. This is to avoid the possibility of traffic travelling on the same path but in opposite directions causing interference.

3.4 Grid-based allocation

A grid of channel squares is superimposed on the terrain in a repeating fashion as that illustrated below in Figure 2: This could eliminate most of the forwarding interference and more importantly interference from adjacent grid squares. Given the x and y of the current grid square the node is in, the channel for use by a particular node given c channels is defined in equation 2 below:

$$C_{x,y} = c(y \bmod \sqrt{c}) + x \bmod \sqrt{c} \quad (2)$$

In this scenario we have assumed the top-left of the simulation area to be the start of the grid. However, in real scenarios the problem arises of deciding how best to allocate the channels. If we have 25 channels in a five-by-five arrangement, the question is of where to start the top left hand side of that grid. Usually nodes use some form of collaboration with other nodes in the network which incurs extra unwanted network overhead; however, given one's latitude and longitude (from a GPS device), we could split the world up into squares so that they fit the above criteria. To our knowledge this has not previously been looked at

Given the information on the shape of the Earth as described by the WGS84 [7] datum, we simplify this slightly by assuming the earth is a perfect sphere with radius (R) halfway between that of the semi-major a and semi-minor b axis. Distances between lines of latitude stay constant so these can easily be divided whereas distances between lines of longitude decrease as one's latitude increases, so the square size in longitudinal degrees must be recalculated for each 100m we travel in latitude. In addition, we need to fit the correct number of squares in, so the square width may need to be altered slightly. Whilst it is possible to divide the world up exactly into squares as the HealPix [8] project has shown, channel allocation needs only to be locally optimal, and slight errors between grid square sizes cause negligible effect. Therefore, we are less constrained in how the squares are allocated and show a method that provides optimality in localities.

Firstly, we derive the equations for calculating which channel (C) to use given one's latitude (φ), longitude (λ), square width and height in metres (G) and the number of channels per column/row in the $c \times c$ grid (c) that is to be overlain:

The number of degrees of latitude that make up a distance of G is:

$$\varphi_d = \frac{360G}{2\pi R} \quad (3)$$

The row someone is on can therefore be derived as:

$$y_\varphi = \frac{2\pi R(\varphi + 90)}{360G} \quad (4)$$

Given the following equation for calculating distances across a sphere:

$$d(\varphi_1, \lambda_1, \varphi_2, \lambda_2) = R \cos^{-1} \left(\sin \varphi_1 \sin \varphi_2 + \cos \varphi_1 \cos \varphi_2 \cos(\lambda_1 - \lambda_2) \right) \quad (5)$$

Substituting in G :

$$G = R \cos^{-1} (\sin^2 \varphi + \cos^2 \varphi \cos \lambda_d) \quad (6)$$

Now we can solve to find the number of degrees in longitude (δ_φ) at latitude (φ) that comprises G metres.

$$\delta_\varphi = \cos^{-1} \left(\frac{\cos \frac{G}{R} - \sin^2 \varphi}{\cos^2 \varphi} \right) \quad (7)$$

Given this, we can now calculate our x co-ordinate:

$$x_{\varphi, \lambda} = \frac{\lambda + 180}{\delta_\varphi} \quad (8)$$

Using these x and y coordinates we can now calculate C using equation 2. The number of squares fitting in a particular row may not be divisible by the number of channels; in this case, nodes should alter the square width slightly to avoid a suboptimal allocation at the meridian line. This alteration of square width would be of the order of a few millimetres.

4. METHODOLOGY

Simulation is widely regarded as an accepted form of analysis for wireless networks due to the impossible complexity of modelling them mathematically. Therefore, we use the established and widely used simulator Glomosim v2.03 [9]. We set up a scenario to simulate that of a static 500m² area with 50 static nodes. Ten-percent of the nodes chosen at random generate traffic and send it to a random destination. The simulation is modified to simulate each of the approaches discussed and compare their results over 60-seconds. The communication range of each node is set at 140m to approximate that of a built up area. The offered load is varied to show how the different approaches cope with different amounts of traffic and to show the existence of a general increase or decrease in performance.

5. RESULTS

We compare the performance of our suggested techniques against the standard one channel. Throughput is normalised against the throughput of a single channel implementation, while offered load is normalised against the maximum capacity of a single-hop wireless link.

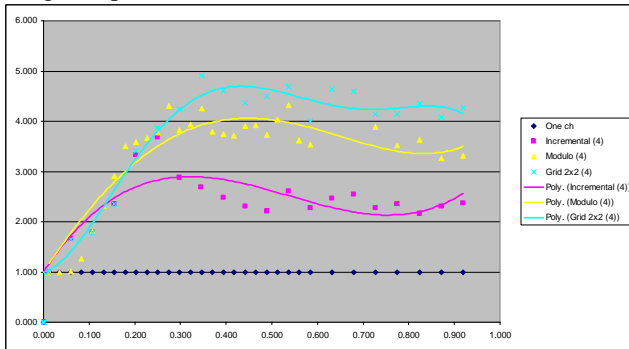


Figure 3: Four channel comparison

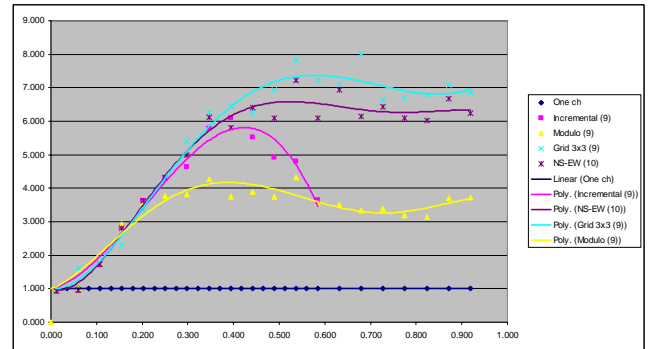


Figure 4: Nine channels and NS-EW (10chs)

Figure 3 compares the modulo, 2x2 grid and the incremental techniques. Grid outperforms all of the others suggesting that spatial re-use is of the utmost importance. compares modulo, incremental and grid using nine channels and also that of NS-EW which uses ten channels. Interestingly, the grid still outperforms all of the other methods, even though the NS-EW has one extra channel. Interestingly with a larger number of channels modulo no-longer out performs incremental. We explain this as a result that there is little advantage in terms of reduction of interference with modulo when the number of channels begins to exceed five; therefore, it is far more effective to use the maximum channel capacity available.

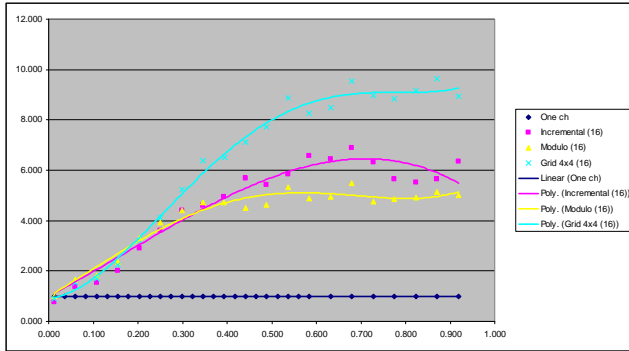


Figure 5: Sixteen channels

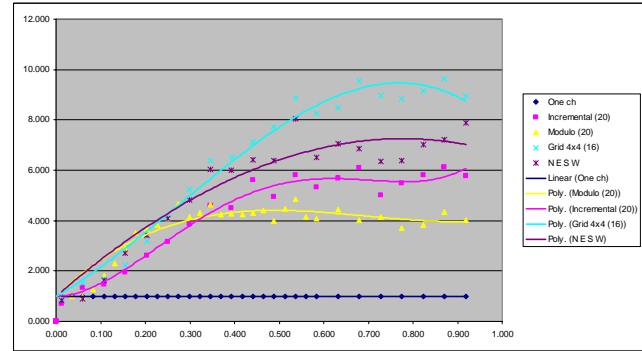


Figure 6: Twenty channels

Figure 5 compares grid, modulo and incremental with sixteen channels; however, it is inappropriate to compare with any of the directional approaches due to the disparity in the number channels used. Again, incremental outperforms modulo for the reasons stated earlier. Figure 6 compares the modulo, incremental, and N-E-S-W approaches using 20 channels. Interestingly, all of these are outperformed by the grid technique using four less channels. The grid approach out performs all of the other methods, even where those methods have a larger number of channels available to them. This supports our theorem that maximising spatial re-use is far more important than maximising capacity.

6. CONCLUSIONS

Spatial re-use in ad-hoc networks is the most important aspect when trying to optimise performance. Results show that optimising spatial re-use performs far better than allowing the use of 10 channels simultaneously at any node. We proposed several approaches to optimise spatial re-use that relies upon only locally available information. All of these approaches performed as well as the commonly cited grid-based approach that is much more difficult to implement.

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