Analysis of the Topology for Moving Wireless Networks

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Abstract

This document presents an analysis of the factors that influence the network topology in a broadband mobile wireless as hoc networks moving on platforms. This paper focuses on studying the topology for networks where the nodes carrying the access points are constantly moving within urban areas. The influence of the number of nodes as well as the structure of the streets (type of mobility) on the network topology is also studied. To do that, this paper will first present methods to analyze the influence of the velocity of the nodes on the network topology. Second, the implications of number of nodes and type of mobility combination are also analyzed. When there are more nodes in a certain type of mobility area, it is expected that the topology of the network follow that structure shape.

1. Introduction

Most of the time, network topology has been considered as fixed aspect on mobile networking. This paper presents the aspects to consider when the topology of the network is constantly changing due to the movement of the nodes carrying access points. This paper shows that there are two main aspects to consider when it happens. Those aspects are the velocity of the nodes as well as the number of nodes and type of mobility combination. When the number of nodes increases it is expected to the type of mobility influence more the topology of the network.

To show the aspects that influence the topology, this paper is organized as follows. The first section analyses the methods to follow to analyse the implication of the velocity of the nodes on the changing topology. The second section analyses the implications of the type of the number of nodes and the type of mobility combination on the topology structure. Then, conclusions are presented.

It is also important to note that in order to define the topology of a network, it is necessary to know the connectivity between the nodes within the network. This connectivity is usually mathematically known as matrix of connectivity and it shows how the nodes are connected between them [2]. For example, if the nodes with a network are connected as the Figure 1 is showing:

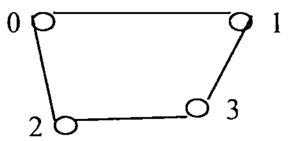


Figure 1. Nodes Connectivity of a Network

Then, the matrix of connectivity is:

$$C_m = \begin{bmatrix} 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 \end{bmatrix} \quad (1)$$

The ones indicate that the nodes are connected and the zeros mean that the nodes are not connected.

2. Network Topology Analysis

This part of the document will present the study of the topology for a mobile wireless network. The required aspects to analyse the topology are also included. Those aspects are the type of mobility and velocity of the vehicles taken into account. Here vehicles as cars, buses and trains are considered. It is also important to note that this analysis will focus on vehicles moving within urban areas.

Furthermore, the distribution of the access points (APs) in a mobile environment in an urban area will be analysed in order to study the structure of the network to build.

Velocity and type of mobility are the two main aspects to consider in order of predicting the topology of a mobile wireless network (MWN), where the access points (AP) are constantly moving. The vehicles which carry the AP move at different speeds, depending on the kind of roads in the area (freeways, high/-slow speed streets and streets with traffic lights). These nodes also move according to certain types of mobility, which is usually determined by the city area model of the roads (Manhattan, random, circular, spiral, cross and group mobility).

It is necessary to sense the speed of the vehicles in the area of communication in order to know how often the topology of the nodes needs to change to maintain communication and the quality of the signal. In order to provide good quality of signal and maintain communication, the nodes communicate with each other within their areas of coverage.

2.1. Velocity Analysis

In the case of vehicles like buses and automobiles (road vehicles), to analyze the velocity and find how often the configuration of nodes or the topology change during certain periods of time, a state model is proposed. It is however important to select appropriate states in order to find the information that needs to be obtained. It is how often the position of the nodes needs to be found to then create the structure of connectivity (topology of the network). To do this, different states diagrams can be considered. For instance, the number of states can be three as Figure 2 shows. These three states represent: the moments when the node is static, when the node is changing velocity and when the node moves at constant velocity. Another states diagram configuration is when different velocities of the vehicle are considered. It includes four states as in Figure 3. In both cases, the important aspects to study are the amount of time in which the vehicle tends to remain in each state and the time that the mobile node takes to go from one state to another. During these times, it is also important to study the connectivity between the nodes. This connectivity will depend on the distance between the APs. In this form, the coverage of the AP is considered.

The two proposed state models are studied in order to determine the more accurate. The first model contains three states. The probability of changing from one state to another is represented in the matrix (2). In Figure 2, there is no connection between the states 0 and 2. This is due to the fact that the node cannot go directly from the static state to a high constant velocity (or vice versa), without first increasing or reducing its velocity in the state 1. The probabilities to change from the state 0 to the state 2 and vice versa are zero.

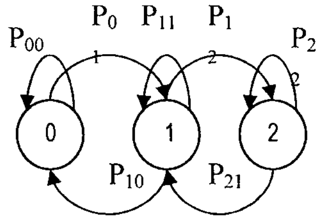


Figure 2. Three states diagram model for vehicles velocity

The three considered states are:

State 0: when the vehicle is static.

State 1: when the vehicle is changing velocity (reducing or increasing velocity).

State 2: when the vehicle moves at constant velocity.

The probability to go from one state to another is represented in the following matrix:

$$S_p = \begin{bmatrix} p_{00} & p_{01} & 0 \\ p_{10} & p_{11} & p_{12} \\ 0 & p_{21} & p_{22} \end{bmatrix} \quad (2)$$

The second model is the probability of four velocity groups as is shown in Figure 3. This four states diagram shows the connections between the states as well the probability for each connection. As it can be seen from the figure, it is necessary to go in a sequential order to move between the different states. It is because the vehicles cannot change the velocity from 0km/hr (state 0) to 80km/hr (state 3) or vice versa instantaneously. It needs first to go from 0km/hr-40km/hr and 40km/hr-80km/hr states or vise versa as the connections in the states diagram shows. Therefore, the probabilities to connect the states jumping between them are zero as the matrix (13) shows (P02, P03, P13, P20, P30 and P31).

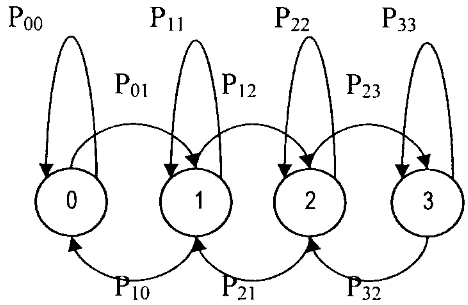


Figure 3. Four state diagram model for nodes velocity.

The four considered states are:

State 0: when the velocity of the bus is 0 km/hr.

State 1: when the vehicle moves at very low velocity (0km/hr to 40km/hr).

State 2: when the vehicle moves at high velocity (40km/hr to 80km/hr).

State 3: when the vehicle moves at very high velocity (80km/hr above).

The following matrix represents the probability to go from one state to another:

$$S_P = \begin{bmatrix} p_{00} & p_{01} & 0 & 0 \\ p_{10} & p_{11} & p_{12} & 0 \\ 0 & p_{21} & p_{22} & p_{23} \\ 0 & 0 & p_{32} & p_{33} \end{bmatrix} \quad (3)$$

The state diagram in the case of the train network scenario will present two states (see Figure 4). Trains usually are moving or at the different stops. In this diagram all the connections between the states are possible as the diagram in the Figure 4 shows. The matrix 4 illustrates the matrix of probability in the case of the mentioned train state diagram.

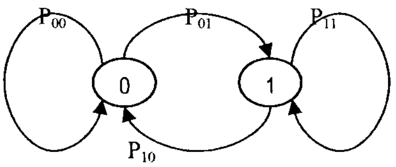


Figure 4. State diagram model for the case of trains

State 0: when the train is stationary at the station.

State 1: when the train is moving.

The probability to go from one state to another in the train scenario is represented in the following matrix:

$$S_p = \begin{bmatrix} p_{00} & p_{01} \\ p_{10} & p_{11} \end{bmatrix} \quad (4)$$

The values of the probability of the matrixes are represented by the formula 5 (below)

$$p_{ij} = \frac{t_{ij}}{\sum_{l=0}^{M} \sum_{k=0}^{N} t_{kl}} \quad (5)$$

Where is the value of the probability to go from one state to another, is the total time that the vehicle takes to go from one state to another and is the sum of the time of all probabilities.

To determinate the values of these probabilities for both road vehicles and trains network scenarios, velocity test are being conducted in cars and on trains. For the case of road vehicles scenario the test is effectuated by driving around different suburbs in Sydney- Australia. To measure the velocity of a vehicle network in different roads of a city area, a Global Position System (GPS) is used. A software called Nemo is used to collect the data. A fixed route is determined, in order to repeat the measurements for different days. Figure 5 shows the selected area to effectuate this analysis. As the figure shows the area presents different kinds of roads:

1. Freeway (#2 oval in the figure).
2. High speed roads with traffic lights (#3 oval in the figure)
3. Low speed roads (#1 oval in the figure).

The figure also shows different kind of mobility areas such as random, Manhattan and cross.

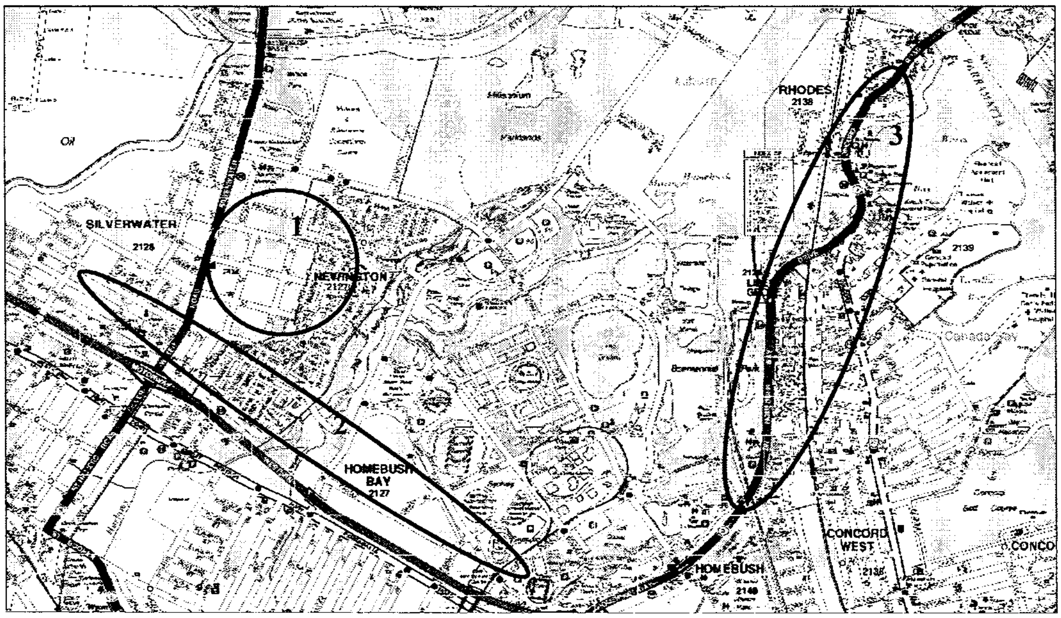


Figure 5. Selected area to drive

Figure 6 shows the workspace that is used in Nemo to take the measurements. In the figure, the dark black line shows the driven road and the black point represents the moving node. "The car parameters" window (bottom in the left) is used to visualize the velocity, time and driven distance.

This recorded information can be replayed many times after finish the test and it helps to collect the data more accurately. All the data is passed to an Excel document to estimate the probabilities in the previously mentioned matrixes.

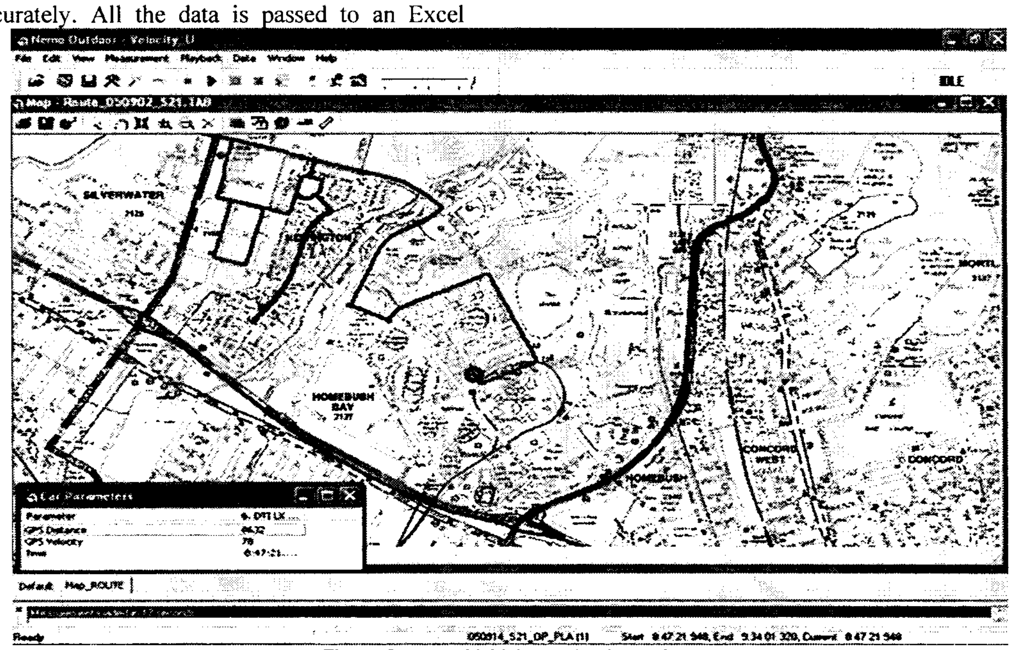


Figure 6. Vehicle moving in a urban area

The used window to visualize the data is shown in the Figure 7. Here, the distance is given in meter, the velocity in kilometers per hour and the time is the current time in which the measurement is taken.

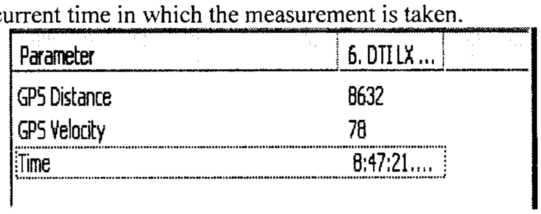


Figure 7. Collected data

Table 1 presents an example of the data collected in an Excel document. The formula 5 is used to calculate the value of the probability of the matrixes.

From the Excel document, the time during the drive in which the vehicle did not move was 205.652 seconds. The total time was 1226.032 seconds. Then, the probability that the node did not move in the matrix (12) of Figure 14 is:

$$p_{00}=\frac{205.652}{1226.032}=0.16773706$$

not moving (sec)	Changing velocity (sec)	constant velocity (sec)
29.576	8.652	9.9
2.501	25.32	60.797
3.328	41.061	10.07
12.975	41.06	
12.454	12.454	
10.86	32.877	
10.22	13.588	
31.192	8.209	
60.102	68.816	
17.809	10.146	
14.634	48.388	
	79.345	
	17.448	

Table 1. Time recorded for the three states diagram model for vehicles velocity

For the case of the four states diagram for node velocity model, the process is the same and the example of the collected data is in Table 2. From the Excel table, the probability in which the node velocity remains between 0km/hr and 40km/hr is calculated as follow:

$$p_{11}=\frac{352.572}{1226.032}=0.301198911$$

0km	0km-40km	40km-80km	80km+
29.576	7.186	11.366	54.116
2.501	25.3	40.837	

3.328	10.979	17.361	
12.975	23.70	28.768	
12.454	12.454	7.169	
10.86	32.877		
10.22	13.588		
31.192	8.209		
60.102	109.035		
17.809	48.388		
14.634	1.72		
	21.411		
	20.277		
	17.448		

Table 2. Time recorded for the four states diagram model for nodes velocity

Then, the same process is followed in order to calculate the rest of the probabilities.

In the cases of the train scenario the data is measured in different train lines in Sydney-Australia are being conducted.

2.2 Mobility Analysis

The type of mobility describes the structure of the roads in different cities or part of the cities. Sometimes, the kind of roads is matched to a type of mobility according to the shape they usually present. For instance, freeways usually have more than two lanes in each direction. In addition, routes and timetables of the public transport vehicles are the main aspects to consider when the type of mobility is analyzed.

In the figures 8 to 13 the blue dots represent vehicles that are not carrying access points (AP) while the red dots represent vehicles that are carrying APs. The position of the cars carrying APs is assumed to be a random event as well as the traffic of the transmission from the vehicles.

First of all the freeway type of mobility, is well known as a chain network mobility structure as shown in Figure 8. The mobile nodes carrying AP are in random position. The black lines show a possible network topology connecting the APs (black points). However, the connection between the APs will depend on aspects such as the distance between the APs (area of coverage) and the congestion in the APs. In fact, the communication between the different mobile nodes can take place in all directions. Therefore, if the nodes communicate in both directions the congestion is expected in the APs located in the middle. If the communication between nodes is mostly in one direction, the congested nodes will be the last one of the end in the direction of the communication. These aspects need to be addressed in order to study the need for using fixed APs along the freeways to minimize the distance and the congestion between APs.

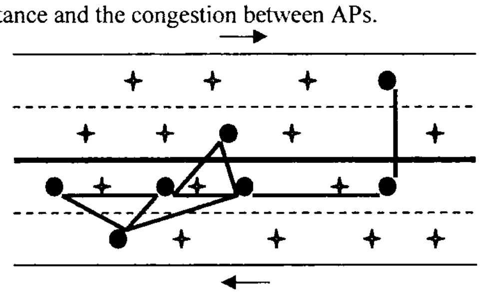
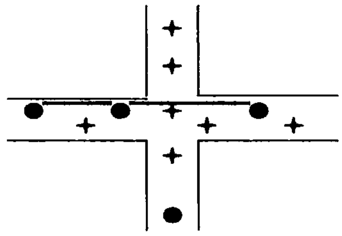
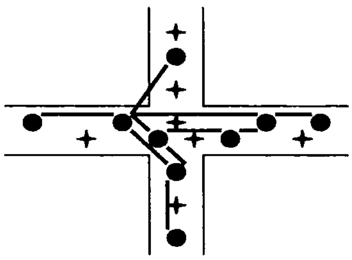


Figure 8. Chain mobility structure

Figure 9 shows the cross mobility structure. The black lines connecting the black points in the figures a) and b) show a possible network topology in these road types. The figure a) shows a cross structure where the represented topology can be just a line, if there are not many nodes carrying APs or if those APs are far apart. However, the network topology will change as soon as the nodes get close enough as it is shown in the figure b), where the cross structure shape have more effect on the network topology. It is due to the increased in the number of APs as well as the reduction of the distance between them. In this type of structure the congestion in the network is expected to be in the middle of the cross, if the communication takes place in all directions.



a)



b)

Figure 9. Cross mobility structure

Figure 10 shows the Manhattan mobility structure which is used in many cities or areas of different cities around the world. The figure shows a possible topology in this mobility structure (black lines connecting the black points). This mobility structure is the result of putting many cross mobility structures together.

Therefore, the congested points are expected to be at the intersection between roads.

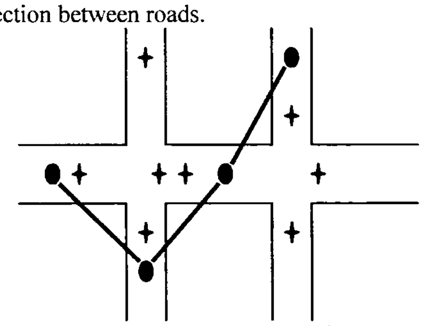


Figure 10. Manhattan mobility structure

Figure 11 shows another kind of network topology in the Manhattan mobility structure. In this figure the nodes are more and are closer to each other than in the previous figure. Therefore, this mobility structure influences the network topology structure more.

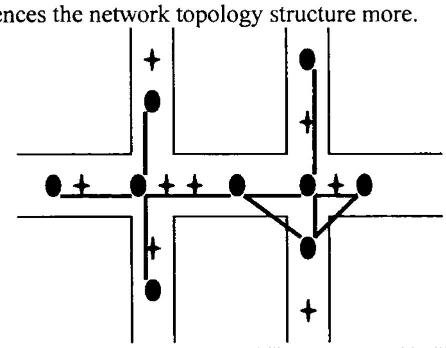
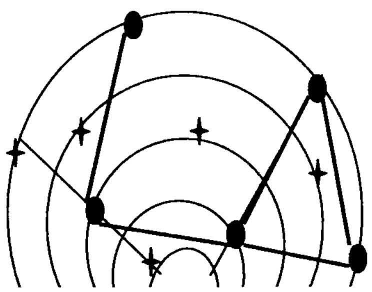


Figure 11. Manhattan mobility structure with different topology

Apart from the mentioned structures, there is the circular mobility structure (Figure 12). The lines connecting the black points show a network topology in this kind of mobility. As the number of APs increases the shape of the network topology will tend to follow the shape of the mobility structure.



In this figure the black lines represent the roads and the dots represent the moving vehicles.

Figure 12. Circular mobility structure

Lastly, the random mobility structure as shown in Figure 13, has an unpredictable network topology even as the traffic increased, therefore it can take any forms of shape.

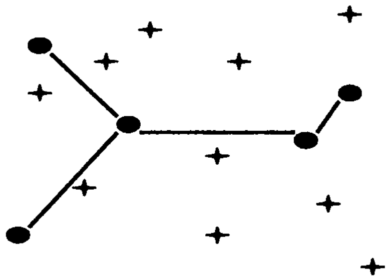


Figure 13. Random mobility structure

3. Conclusions

Based on the previous analysis of different types of mobility structures, it can be concluded that the network topology will be random when there are not much APs in the roads. As the number of APs increases (too many), the resulting network topology will tend to have the shape of the kind of mobility structure of the roads in the area. Therefore, the topology can be predicted according to the structure of the roads in the different areas of the city. An advantage of this changing network topology is that the number of APs is expected to increase in proportion with the traffic on the roads. Therefore, when more users require service in an area more APs points will be available to handle the traffic of the network. However, if the interference increases too much due to the network traffic, the signal will be impossible to recover.

In the case of trains, the kind of mobility depends on the structure of the train system in the city as well as the timetable of the train system.

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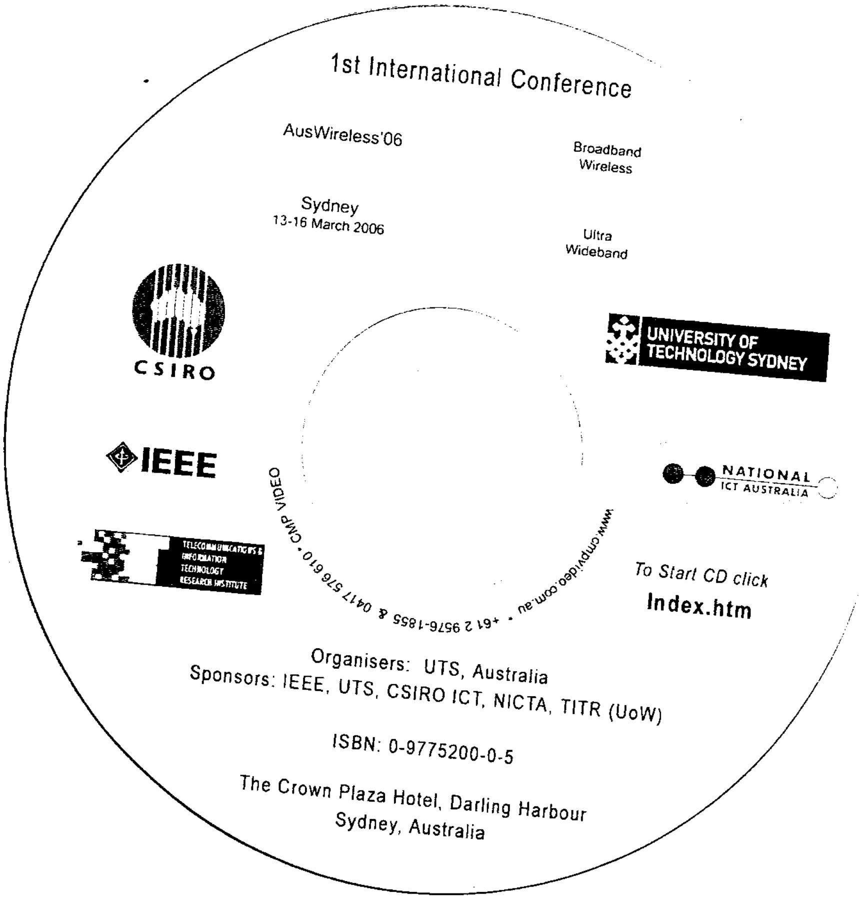

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