A New Switched Beam Smart Antenna Model for Extending Inet Omnet++ Framework

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Abstract: Smart Antenna Systems (SAS) are providing a strong increasing impact in digital wireless communication systems. Due to their great advantages regarding nodes power saving and coverage enhancing, SAS are largely employed on pervasive network environments such as MANET. Because almost the whole of existing network simulators use omnidirectional antennas on nodes, we propose a new version of Inet framework of Omnet++ that extends its operation also for network scenarios in which nodes are equipped with directional antennas. Furthermore, we created a new directional antenna module that simulates the behaviour of a Phased Array System and a very simple algorithm for power management in channel. The new proposed model presents some modifications to key-modules that are involved in a normal wireless communication scenario, in order to support asymmetrical communications between nodes.

1 INTRODUCTION

Since the early days of wireless communications, focusing on physical layer of a network node there are two main kinds of antenna that can be used for equipping it in order to produce a certain behaviour on transmission/reception: omnidirectional antennas, which radiates and receives equally in all directions, and directional antennas which are capable to radiate in a fixed particular angular direction. Omnidirectional strategies directly and adversely impact spectral efficiency, limiting frequency reuse (Chu, 1948). These limitations force system designers and network planners to devise increasingly sophisticated and costly remedies. In recent years, the limitations of broadcast antenna technology on the quality, capacity, and coverage of wireless systems have prompted an evolution in the fundamental design and role of the antenna in a wireless system. In low power design systems, such as Manet or Sensor Networks, using an omnidirectional approach it is a difficult and inconvenient way to produce efficient systems, because the high amount of power consumption of network nodes (Khuzhali, 2014), that could be translated in overcome phenomena such as low battery lifetime and interference generations. A single antenna can also be constructed to have certain fixed preferential transmission and reception directions in order to maximize its energy consumption in a particular direction saving power in other directions (Nasipuri-Sappidi, 2002). Using directional antenna there could be several advantages, in terms of reduction of reception packet delay or performance enhancing of a routing protocol (Dimitrou-Kalis, 2004). In conventional wireless communications, a single antenna is used at the source, and another single antenna is used at the destination. This is called SISO (Single Input, Single Output) (Sengar-Rani-Singhal-Sharma-Verma-Singh, 2014). In later years, it has developed the concept of Smart Antenna Systems intended as a particular System that is capable to be “intelligent” basing on physical and logical implementation features. This kind of systems can increase the coverage area and the capacity of a wireless communication system. The coverage area, is simply the area in which communication between a mobile and the base station is possible. The capacity is a measure of the number of users a system can support in a given area. The employment of SAS in wireless mobile environments allows a more efficient medium utilization with respect to the classical Omnidirectional approach. For example, Spatial Division Multiple Access (SDMA) seeks to increase the capacity of a system. Generally, Smart Antennas fall into three major categories: SIMO (Single Input, Multiple Output), MISO (Multiple Input, Single Output), and MIMO (Multiple

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Input, Multiple Output). In SIMO technology, one antenna is used at the source, and two or more antennas are used at the destination. In MISO technology, two or more antennas are used at the source, and one antenna is used at the destination. In MIMO technology, multiple antennas are employed at both the source and the destination. A Smart Antenna System combines generally an antenna array with a digital signal-processing capability to transmit and receive in an adaptive, spatially sensitive manner. In other words, such a system can automatically change the directionality of its radiation patterns in response to its signal environment. This can dramatically increase the performance characteristics (such as capacity) of a wireless system. One of the most critical aspect in wireless communications environments is represented by the fact of using an adequate network simulator that is able to well emulate and reproduce an appropriate real scenario. Unfortunately, most of the existing network simulators do not provide any support for directional and asymmetrical communications and thus also for SAS technology. For this reason, in the present work we propose a model that extends the functionalities of *Omnet++* simulator in order to provide a useful support for asymmetrical communications and Smart Antenna Systems. The paper is structured as follows: section 2 introduces SAS main principles; section 3 is an overview about existing network simulator compared to *Omnet++*. In sections 4 and 5, the proposed model and the proposed algorithm are presented respectively. Finally, in section 6 simulation results are discussed.

2 SMART ANTENNA SYSTEMS (SAS)

As mentioned, SAS are intelligent systems that allows a good SDMA processing (Wei, 2004); examples of SAS are: digital beamforming systems, adaptive antenna systems, phased array and others. Smart antennas are customarily categorized, however, as either switched beam or adaptive array systems. There could be a distinction between the two major categories of smart antennas in term of the operation mode (Kulkarni-Bhavani, 2014); (Balanis-Ioannides, 2007):

- *switched beam*: a finite number of fixed, predefined patterns or combining strategies
- *adaptive array*: an infinite number of patterns (scenario-based) that are adjusted in real time

So, these strategies differ between beamforming building technology. Switched beam antenna systems form multiple fixed beams with high sensitivity in particular directions. These antenna systems detect signal strength, choose from one of several predetermined, fixed beams, and switch from one beam to another as the mobile moves throughout an area. So, they produce a static fixed beam that could be electronically controlled. Adaptive antenna technology, instead, uses adaptive algorithm because of its ability to effectively locate and track various types of signals to dynamically minimize interference and maximize the intended signal reception. In this case, produced beam is variable and adapt itself depending on transmission channel conditions and a weight array that dynamically varies in time. In this context, the spatial structure is used to estimate the direction of arrivals (DOAs) or AOA (Angle of Arrive) by nodes. However, both systems attempt to increase gain according to the location of the user; We can synthetize the operating Smart Antennas principle with the following figure (Wei, 2004):

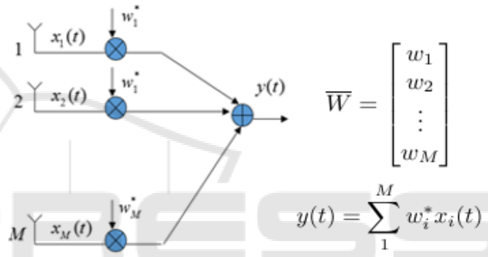


Figure 1: Smart Antenna general operation schema.

Inputs $x_1 \ldots\ldots x_M$ are combined each one with element values of a weight array that varies according to an adaptive algorithm (for example LMS or CMA), so output *y(t)* is a variable beam in adaptive array systems. Using a switched beam approach there is no adaptive algorithm execution and weight array can be considered missing or constant, beam is fixed but it is very simple to realize with worse performance than adaptive array systems of course.

3 NETWORK SIMULATORS OVERVIEW AND OMNET++

There are several network simulators (Chirstu-Namrata-John-Shibin, 2013) that could be used for creating a network mobile scenario containing nodes that are equipped with a particular kind of antenna system; some of the most used software are: *Ns2, Ns3, Opnet, Omnet++*. *Ns2* (Charbonneau, 2010) follows two levels of hierarchy namely C++ Hierarchy and the interpreted OTcL, which is one to one correspondence. Two languages are linked to achieve a higher efficiency. *Ns3* (NS-3, 2014) is a discreet-event simulator primarily targeted for research and educational purposes. *Ns3* is not an extension of *Ns2*; the similarity between *Ns2* and *Ns3* are both written in C++ Codes but *Ns3* does not support *Ns2* API. *Ns3* simulator is written in C++ and python. *OPNET* (Dunaytsev, 2012) is another network simulator, which provides a better User Interface than *Ns2* and *Ns3*. *Omnet++* (Omnet++ User Manual, 2016) is a discrete event simulation environment. *Omnet++* provides component architecture for models. Components (modules) are programmed in C++, and then assembled into larger components and models using a high-level language (NED). Reusability of models comes for free. Logical behavior of modules is generally written in .cc and .h files containing all logical functions. Because its simply features, and because this simulator enhanced and improved during years with some users contribution, therefore considering that it is extremely intuitive from user interface point of view we choose to use *Omnet++* 4.6 for our test simulations. For our purpose, we used *Inet* framework that provides a very complete modules and protocols choice especially for Mobile Networks. Unfortunately, *Omnet++* does not support asymmetrical communication between nodes (Uribe-Maureira-Dalle, 2010), so we need to modify some logical modules configuration in order to achieve our purpose. In this way, we would extend *Inet* framework in order to make it able to work with directional antennas equipped nodes, and so for smart antenna systems. We used a different approach with respect to (Uribe-Maureira-Dalle, 2010) in which a *Neighbors Graph* Algorithm is created for power management therefore modifying *channelControl* module (no longer available in current version of *Omnet++*). In (Uribe-Maureira-Dalle, 2010) For supporting directional communications between nodes, a *DirectionalRadio* module is created for obtaining a directional antenna pattern; in our work, instead, we created a new directional antenna model and next a simple algorithm for power management that allows a "not static" assignment of nodes power. Furthermore, the version of *Omnet++* used in this work deeply differs from 4.2 version used in (Uribe-Maureira-Dalle, 2010).

4 PROPOSED MODEL

Our model is based on the simplest SAS technology that is the Switched Beam approach. Differently from (Inzillo-De Rango, 2016) in which a MAC layer analysis is accomplished, this work provides for modifications on physical layer only. Firstly, we created a new directional antenna module called "*PhasedArray*". This module, like other models, extends *AntennaBase* module. It was created based on Antenna Array theory, implementing in *computeGain* function the following formula (Patel, 2007):

$$G(\theta,\varphi)_{TOT} = G(\theta,\varphi)_{EF} * G(\theta,\varphi)_{AF} \tag{1}$$

Where the first term is referred to element factor gain, and the second term is the array factor gain. Array factor is the main term conditioning System Array behavior, and its module could be expressed as follows (Orfanidis), for linear uniform arrays:

$$\mathrm{AF} = \left| \frac{\sin\left(N\psi/2\right)}{\mathrm{N}\sin\left(\psi/2\right)} \right| \tag{2}$$

Where:

$$\psi = kd(\cos\phi - \cos\phi_0) \tag{3}$$

k is the wavenumber, *d* is the distance between each radiating elements and φ_0 is the steering angle, that is the angle corresponding to maximum directive gain of radiation pattern depending on radiating elements number (N) too. We suppose that all elements produce the same pattern and we choose an element factor EF = cos θ. Because *Omnet++* is not able to produce radiation pattern figure for antenna modules, we produce a simple *matlab* code implementing above expressions. For instance, for N=10, $\varphi_0 = 120°$, f = 1 MHz, d = 0.5λ we have the following situation:

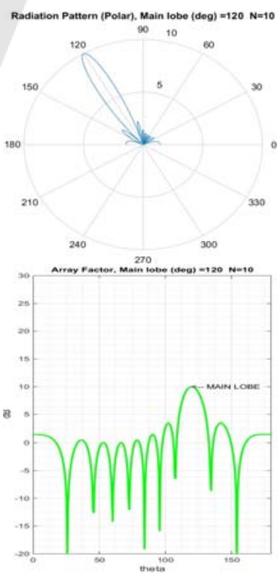


Figure 2: Array Factor plots for N=10, $\varphi_0 = 120°$, d = 0.5λ: (a) polar plot; (b) rectangular plot.

Where φ_0 varies from -180° to 180°. Fig. 2(a) represents an example of Array Factor polar gain, with main lobes pointed to steering angle absolute value. Fig. 2(b) represents Array Factor rectangular plot of the whole Phased Array system.

5 MODIFICATIONS ON INET AND PROPOSED ALGORITHM

We created a new macro network module called *AODVNetwork2* that simulates a scenario for MANET. Of course, no smart antenna submodule exists in *Omnet++* and for this purpose we modified these existing modules in order to support asymmetrical communications too. Primarily, we modified the module related to mobile network nodes, so we used an array of *StandardHost* called *host* having a size equal to the number of nodes involved in our simulations. On physical layer, we modified the *ScalarAnalogModelBase* Class that implements Free Space Model Path Loss for propagation and we created and inserted an algorithm in this class for node power management in order to create a dynamic power quantity assignment based on transmission direction and angular position of each node. It is recalled that *Omnet++* does not support asymmetric communication between nodes, so by default, for each node the power value is the same for all directions. We modified *computeReceptionPower* function in order to implement Free Space PathLoss Model that satisfies the relation:

$$P_{rx} = P_{tx}\, G_{tx}\, G_{rx}\, L_{Path} \qquad (4)$$

Given a transmitter node A and a receiver B, if A transmits with a steering angle φ_0 towards B, B will receive with an angle $\varphi' = (\varphi_0 - 180°)$ if $\varphi_0 \geq 0$ or $\varphi' = (\varphi_0 + 180°)$ if $\varphi_0 < 0$; So, receiver node B, in this case, gets an estimation of AOA based on transmission direction of A, and adjusts its beam in order to maximize its reception power:

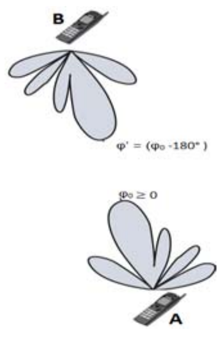


Figure 3: AOA estimation principle.

Next, we created an algorithm for dynamic assignment power for each *host* based on the main beam direction and so on transmission/reception direction position coordinates of nodes. For a given node that produces a radiation pattern forming a beam with main lobe angle φ_0 it will transmit/receive with a power value that will be the maximum or a fraction of this according to radiation pattern form.

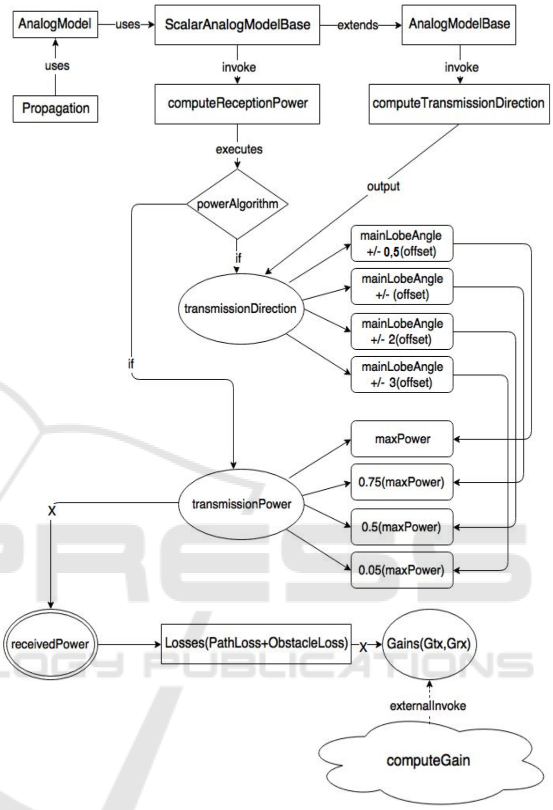


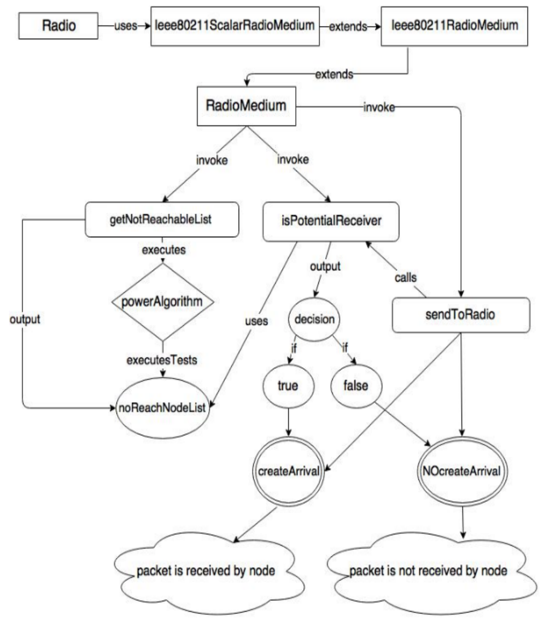
Figure 4: Logical block schema 1.

The proposed algorithm takes into account also of the sidelobes amplitude of the pattern, so it has implemented a classification level of side lobes based on transmission/reception direction angle value. In Fig. 4 it is shown a logical block schema that illustrates the main steps and modules about modifications accomplished on implementation level basis: Rectangle forms contain modules or class names; rounded rectangles contain class functions names or variables names; elliptics contain only output variables names; double rounded elliptics contain only output variables of a key function, and it can be considered as a final state of an automata. In Fig.4 we note that *ScalarAnalogModelBase* extends and so implements all functions of *AnalogModelBase* Class. In *ScalarAnalogModelBase* there is a function *computeReceptionPower* that assigns the power value to nodes, basing on angle position direction of a receiver node with respect to a transmitter node; so, it makes a test comparing main beam angle to *transmissionDirection* value that is the return value of *computeTransmissionDirection* function invoked in *AnalogModelBase* Class. The test is carried out by a power Algorithm that assigns a power value depending on *transmissionDirection* value. The following pseudo-code better illustrates the Algorithm's operations:

```
Algorithm 1 Power Algorithm procedure
procedure POWER ALGORITHM
    int offset=getOffset();
    double transmissionDirection = computeTransmissionDirection();
    double transmissionPower;
    if ( -0.5*offset<=transmissionDirection <= 0.5*offset ) then
        transmissionPower= scalarSignalAnalogModel.getPower();
    else if ( -offset<=transmissionDirection <= offset ) then
        transmissionPower= 0.75* scalarSignalAnalogModel.getPower();
    else if ( -2*offset<=transmissionDirection <= 2*offset ) then
        transmissionPower= 0.5* scalarSignalAnalogModel.getPower();
    else if ( -3*offset<=transmissionDirection <= 3*offset ) then
        transmissionPower= 0.05* scalarSignalAnalogModel.getPower();
    else
        transmissionPower=0;
    end if
end procedure
```

Figure 5: Power Algorithm Pseudo-Code.

An important parameter for the algorithm is the *offset* variable. This value is function of two parameters: the *mainLobeAngle* (commonly referred to φ_0) and the *spreading factor*. The first term, as already mentioned, represents the angle of maximum radiation, and its value is returned by the *getPhizero* function implemented in the *PhasedArray* module. The second term varies from -1.5 to 2 according to the number of radiating elements of the array. In particular, the larger is the number of elements, the greater is the *spreading factor* value. This feature allows to take into account of the spreading effect that affects the overall pattern varying the number of elements. Setting an appropriate offset helps to enhance the sidelobes research within the beam and their classification process. From Fig. 5 it can be observed that, based on the *transmissionDirection* value, the power is fractioned opportunely. If the *transmissionDirection* value is not related to any sidelobe level, the power is reduced to 0. This algorithm is static and approximated, but more flexible, in fact it also takes into count main beam pattern, that is a function of elements number antenna array. Some modifications are accomplished in *RadioMedium* module, so we show another logical block schema that synthetizes all functions and modules that are involved in:



Figue 6: Logical block schema 2.

RadioMedium class, contains a remarkable number of functions that drives control of traffic flows passing through the network. We created a *getNotReachableList* function that executes *powerAlgorithm* and returns the complete list of nodes that cannot be reached by a transmission due to their current position with respect to transmitter position. *isPotentialReceiver* function uses this list for determining if a given receiver is reachable or not by a transmission, and gives a Boolean output according to the content of list returned by *getNotReachableList* function.

6 MODEL VALIDATION AND SIMULATION RESULTS

For validation of the designed model we chose to consider a configuration containing only 10 mobile nodes, and successively extend our model to configurations with an increasing nodes number. Due to space limitations, we will show and discuss only results relative to 10 nodes configuration. The following table synthesizes main simulations parameters of this configuration; these parameters are extracted from *.ini* file and may be modified for every need:

Table 1: Setting of parameters used in simulations.

Manet Routing protocol	AODV
Antenna Type	Phased Array
Antenna Freq.	1 MHz
Distance	0.5 λ
Number of Elements	10
Number of Nodes	10
Main Beam Angle (Phizero)	7°(rc1),102°(rc2)
ConFig. Mobility	Static
Simulation Area Size	500 x 500 m
Simulation Time	300 s

As we can observe, distance between each radiating element is a good set for avoiding Grating Lobes in radiation pattern; position of each node is randomly generated by *Omnet++*; for simplicity, only *host 7* generates UDP traffic and sends it to *host 0,1,3,5* that are receiver nodes. Because results depend on angular position and so on transmission direction of each node with respect to each other, firstly we created an utility module *Mempos*, to take into account the current position of the node and for generating a matrix that maintains the current position angle between all nodes, that is useful for evaluating simulations results. As follows, we show the so called "*transmission directions matrix*" generated from *Mempos* module. It will be very helpful for results analysis:

	host[0]	host[1]	host[2]	host[3]	host[4]	host[5]	host[6]	host[7]	host[8]	host[9]
host[0]	-	68°	-10.48°	36.17°	49.79°	84.2°	60.94°	55.66°	80.29°	48.13°
host[1]	-112.1°	-	-69.41°	-19.41°	-3.762°	-129.9°	-39.75°	-77.48°	-137.2°	4.076°
host[2]	169.6°	110.7°	-	76.92°	90.89°	136.5°	107.3°	113.4°	128.5°	85.67°
host[3]	-143.9°	160.7°	-103.2°	-	139.1°	-169.6°	165.4°	-172.4°	-178.3°	115.1°
host[4]	-130.3°	176.3°	-89.2°	-40.96°	-	-153.2°	-169.5°	-141.3°	-161.8°	31.08°
host[5]	-95.89°	50.2°	-43.61°	10.5°	26.84°	-	36.13°	14.32°	66.59°	27.39°
host[6]	-119.1°	140.3°	-72.83°	-14.65°	10.58°	-144°	-	-99.05°	-155.9°	16.33°
host[7]	-124.4°	102.6°	-66.66°	7.72°	38.75°	-165.8°	81.04°	-	171.8°	37.07°
host[8]	-99.8°	42.92°	-51.61°	1.759°	18.31°	-113.5°	24.23°	-8.296°	-	20.18°
host[9]	-132°	-176°	-94.42°	-64.98°	-149°	-152.7°	-163.8°	-143°	-159.9°	-

Figure 7: Transmission directions matrix.

Fig. 7 shows the current transmission direction angle of an *i*-row *host* row with respect to each other *j*-column *host* of the network. Note that angle value varies from -180° to 180°. For example, if *host 0* sends toward *host 1* it transmits with an angle of 68° because its angular position with respect *host 1*. In our simulations, we suppose that *host 7* is the only node that generates any traffic data towards receivers. For understating if the proposed antenna model is well designed we have to compare simulations results with a "default" configuration of AODV model example of *Omnet++* in which mobile nodes are equipped with omnidirectional antennas. As follows it is shown the result related to the received packets when mobile nodes use *IsotropicAntenna* model:

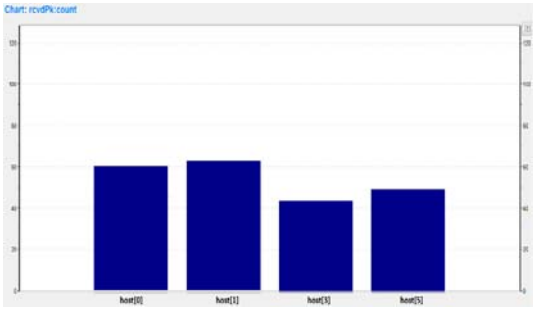


Figure 8: Received Packets Omnet++ Omni Configuration.

From Fig. 8 we can note that all nodes (on receiver side) receive packets. In particular, the overall received traffic is uniformly distributed among nodes. Now, we can replace the default antenna model with our *PhasedArray* model. We created 2 run configurations. The first one (rc1) has main lobe angle pointed to 7°, so, referring to our *transmission directions matrix*, we can expect that generated traffic will be driven towards nodes lying on main lobe region. In particular, among all receivers, only *host 3* is situated in main lobe region. Radiation pattern for Phased array with main beam angle of 7° is shown below:

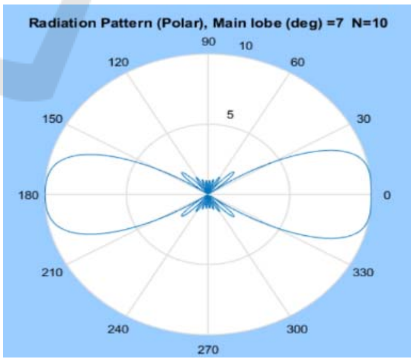


Figure 9: Array Factor Polar Plot for N=10, $\varphi_0 = 7°$, d = 0.5λ.

In Fig. 9 we can observe that sidelobes amplitude is very smaller than main lobe. Because the main lobe degree value is very small, in this case the beam is flattened close to 0. The following figure shows received successful packets statistic referring to all receiver nodes:

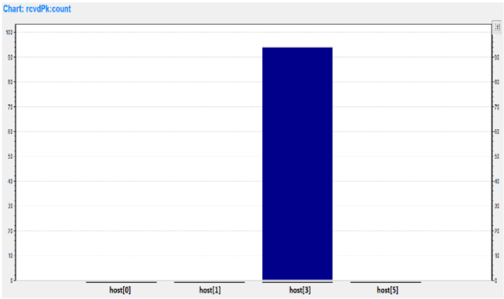


Figure 10: Received Packets Omnet++ statistics (rc1).

As we could expect, data packets flow is directed toward *host 3* because its angular position compared to sender node (*host 7*). Other receiver nodes, have a negligible power reception value, due to their angular position. Furthermore, side lobes amplitude is very low in this case, consequently they are not able to receive packets. Second run configuration presents a main beam angle of 102°, other parameters are the same of rc1. It shows radiation polar pattern in this case:

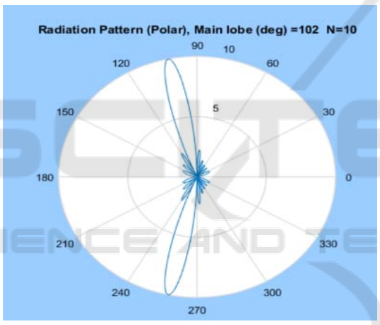


Figure 11: Array Factor Polar Plot for N=10, $\varphi_0 = 102°$, d = 0.5λ.

Now we have maximum side lobes gain of about 2.5 dB, so side lobe power may be not fully negligible in this case. Next figure shows received packets statistic among all receivers:

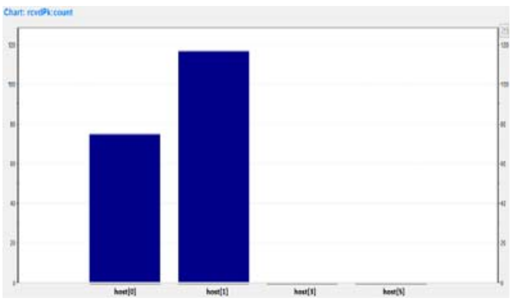


Figure 12: Received Packets Omnet++ statistics (rc2).

In this case, data packets are mainly directed to *host 1* which is situated within main lobe region, but due to power contribution of major side lobes, a fraction of packets will be received by *host 0* also according with our *powerAlgorithm*. In particular, from .log analysis we observed that main side lobes present an amount power of 5 mW that is not negligible with respect to maximum power value in main lobe region of 10 mW. For a further validation of the model we also analyzed the results related to the energy consumption of each receiver node; for this purpose, we inserted energy simulation modules into each mobile node setting the initial energy value of each node to 150 J, and the shutdown energy value to 0 J. For Analyzing the energy consumption of nodes, we collected the Residual Capacity statistics produced by *Omnet++*:

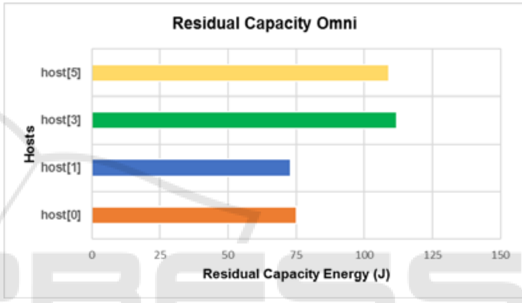


Figure 13: Residual Capacity Omnidirectional Config..

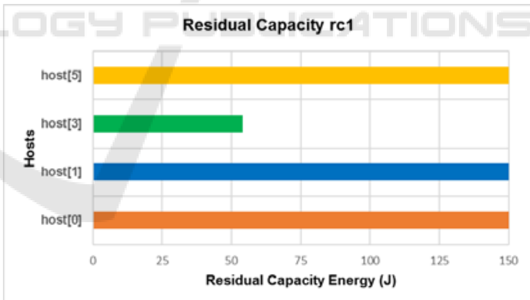


Figure 14: Residual Capacity rc1 Config..

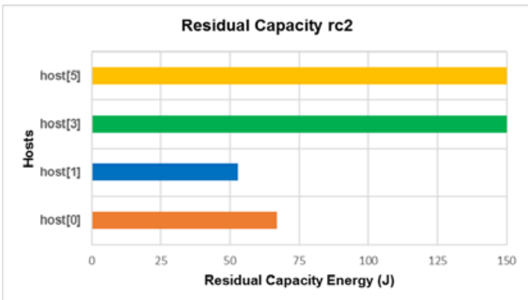


Figure 15: Residual Capacity rc2 Config..

From Fig. 13 we can observe that the energy consumption is uniformly distributed between nodes; in Fig. 14, instead, we can note that the nodes that are not in the main lobe region preserve its energy amount. In particular, all energy is conveyed toward the *host* that is within the main lobe region. Furthermore, in Fig. 15 the energy consumption is preserved, except from *host 0* that suffers from the effect of the sidelobes. Because energy consumption results clearly reflect values obtained in packet statistics, we can conclude that our designed module is functional and could be used for allowing asymmetrical and directional communications as extension of *Omnet++* features. Finally, it is shown a summary Table that compares the main features of the most used network simulators discussed in sec. 3:

Table 2: Network simulators features comparison.

Network Simulator	*Open Source*	*Asymmetrical Comms Support*	*SAS Support*
NS-2	yes	partial	no
NS-3	yes	no	no
OPNET	no	partial	no
OMNET++ (default Inet)	yes	no	no
OMNET++ (our Inet)	yes	yes	yes

Although *Opnet* and *Ns-2* provide some patches to support asymmetrical communications between nodes, they do not provide any Smart Antenna Module by default; therefore, with respect to *Opnet*, *Omnet++* is an open source Software that can be enhanced by developers. In this regard, our work demonstrated that, through some appropriate modifications, *Omnet++* could be improved in terms of features, becoming more useful for end users especially in beamforming and directional antenna contexts.

7 CONCLUSIONS

We proposed to extend *Inet* framework of *Omnet++* simulator adapting original source logical structure also to network systems that supports directional and asymmetric communications. For this purpose, we presented a *Switched beam* smart antenna approach applied to a real network scenario where mobile nodes are equipped with directional antennas. After designing directional antenna module, through several modifications accomplished on original modules, we demonstrated that, applying a very simple algorithm for managing the power of nodes, independently on their positions, we can convey data traffic flows only towards a specific direction; results showed that, using this approach, instead of the classical omnidirectional mode, it can be achieved a considerable energy saving also obtaining a larger coverage range due to gain value in the main beam region. Typically, this value is greater than 1 and depends on geometrical structure of used array. Anyway, when we drive the main lobe in a certain direction, we have to consider the entity of sidelobes. Our analysis, also investigated about this situation, evaluating a case in which sidelobes power value is not negligible with respect to main lobe power; in this regard simulation results demonstrated that some nodes which are not located in main lobe region could receive sent packets. This effect need to be accounted in the protocol design at higher layers such as Mac and Network Layers.

REFERENCES

Chu L.J., 1948 "Physical limitations of omnidirectional antennas, "*Journ.Appl.Phys., vol. 19, pp. 1163–1175*

Khuzhali, S., 2014 "Energy Efficient Topology Based on Demand for MANETS Using Directional Antenna" *Middle-East Journal of Scientific Research*

Dimitrou T., Kalis A., 2004" Efficient Delivery of Information in Sensor Networks Using Smart Antennas", *Chapter "Algorithmic Aspects of Wireless Sensor Networks Volume" 3121. pp 109-122*

Sengar K., Rani N.,Singhal A.,Sharma D., Verma S., Singh T., 2014 "Study and CapacityEvaluation of SISO, MISO and MIMO RF Wireless Communication Systems" *IJETT – Vol.9.*

Kulkarni S., Bhavani V., 2014 "Study on Smart Antenna Systems and Implementation in Mobile Ad Hoc Networks", *IJERA, Vol. 4.*

Balanis C., Ioannides P.,2007" Introduction to Smart Antennas", Lecture #5, Morgan & Claypool.

Wei L.,2004" Smart antennas and MAC protocols in MANET",

Christu M.R., Namrata C., John M., Shibin D. , 2013 "A Comprehensive Overview on Different Network Simulators", *IJET*

Patel P.D., 2007 "Fundamentals of Phased Arrays", *As tron, Netherland*

Orfanidis S.J., "Electromagnetic Waves and Antennas" *Ch.20: Antenna Arrays , Rutgers ECE*

Uribe P., Maureira J.C., Dalle O. 2010 "Extending INET Framework for Directional and Asymmetrical Wireless Communications". *ICST Workshop*

Nasipuri A., Li K., Sappidi, U.R. 2002 "Power Consumption and Throughput in Mobile Ad Hoc Networks using Directional Antennas", *IEEE Int. Conf. on Comm. And Networking*

Charbonneau N.,2010 "Using Tcl and ns2 01/2010 Tcl and ns2: Tutorial"
2014, NS-3 Simulator ns-3 Tutorial Release ns-3.15 ns-3 project
Dunaytsev R. 2012:" Network Simulators OPNET Overview and Examples".
2016, Omnet++ Network Simulator User Manual 4.6 Version
Inzillo V., De Rango F., 2016 "A Directional Mac Approach Extending Omnet++ Simulator", *Summer Computer Simulation Conference 2016 (SCSC), Canada*