Weighted Contention and Interference routing Metric (WCIM)

Report 1: Analysis of WCIM model

Contention- and Interference-Aware Flow-based Routing in Wireless Mesh Networks: design and evaluation of a novel routing metric

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Introduction

Simulator

WCIM

Report1: Analysis of WCIM model

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- OMNET++
  - http://www.omnetpp.org/
  - http://www.omnetpp.org/pmwiki/
  - http://groups.google.com/group/omnetpp?pli=1

  - OMNeT++ is an extensible, modular, component-based C++ simulation library and framework
  - OMNeT++ provides a component architecture for models.
    - Components *(modules)* are programmed in C++, then assembled into larger components and models using a high-level language *(NED)*.
  - Frameworks:
    - **Mobility Framework:** wireless and mobile networks. MF includes a 802.11 model as well as several contributed models: BatteryModule, BMAC, LMAC, IEEE 802.15.4 CSMA (non beacon enabled mode)…
    - **INET**: contains models for IP, TCP, UDP, PPP, Ethernet, MPLS… Mobile and wireless simulations, mostly based on Mobility Framework
      - INETMANET: AODV-UU, DSR-UU, DYMO-UM and OLSR-UM
    - **CASTALIA:** Wireless Sensor Networks (WSN), Body Area Networks (BAN) and generally networks of low-power embedded devices.

- Ned language
  - Example

```
module FixManetHost
   parameters:
      numUdpApps: numeric const,
      udpAppType: string,
      routingFile: string,
      x: numeric const,
      y: numeric const;
   gates:
      in: radioIn;

  submodules:
      notificationBoard: NotificationBoard;
         display: "p=60,70;i=block/control";

      udpApp: udpAppType[numUdpApps] like UDPApp;
                        parameters:
                         time_off = -1,
                         time_end = 1,
                       dest_addresses="random_name(host)",
                         time_begin = 200,
                        time_end = 400,
                         message_length= 11776,
                         message_freq= 0.1570,
                        dscp = 1,
                        burst_duration = 200,
                        rand_generator=1,
                         limit_delay= 1;
                        display: "i=block/app;p=272,67";
      udp: UDP;
         display: "p=272,154;i=block/transport";
                        interfaceTable: InterfaceTable;
         display: "p=60,150;i=block/table";
routingTable: RoutingTable;
         display: "p=60,230;i=block/table";
NetworkLayer: NetworkLayerGlobalArp;
         parameters:
            proxyARP = false;
         gatesizes:
            ifIn[1],
            ifOut[1];
            display: "p=248,247;i=block/fork;q=queue";
manetrouting: ManetRouting;
         display: "p=153,247;i=block/network2";
wlan1: IEEE80211Nic2; // Nic80211 also works, it uses MF's 802.11 implementation
         parameters:
                  mgmtType = "Ieee80211MgmtAdhoc",
                  rate = 12e6;
                  display: "p=248,349;q=queue;i=block/ifcard";
mobility: NullMobility;
         parameters:
                   x=x,
                  y=y;
         display: "p=149,307;i=block/cogwheel";

connections nocheck:
      for i=0..numUdpApps-1 do
         udpApp[i].to_udp --> udp.from_app++;
         udpApp[i].from_udp <-- udp.to_app++;
      endfor;

      udp.to_ip --> networkLayer.UDPIn;
      udp.from_ip <-- networkLayer.UDPOut;

      networkLayer.MANETOut --> manetrouting.from_ip;
      networkLayer.MANETIn <-- manetrouting.to_ip;

      radioIn --> wlan1.radioIn;
      wlan1.uppergateOut --> networkLayer.ifIn[0];
      wlan1.uppergateIn <-- networkLayer.ifOut[0];
endmodule
```

- Initialization parameters
  - Example

[General]
sim-time-limit = 550s
network = grid8021_aodv
num-rngs = 4

[Parameters]
***.numHosts = 64,**
***.nodeSeparation = 140**

udp apps (on) - Genericos
****.host[*].udpAppType="UDPBasicBurst"**
**.host[*].numUdpApps=1
**.udpApp[0].local_port=1234
**.udpApp[0].dest_port=1234

ip settings
**.routingFile="",
**.ip.procDelay=10us,
**.IPForward=true

#METRICS
#WCIM 0, HOPCNT 1, ETT 2, define MIC 3, define CATT 4, define ILA 5
****.host[*].manetrouting.manetmanager.metric_type = 0**

nic settings
**.frameCapacity = 10
**.address = "auto"
**.maxQueueSize = 14
**.rtsThresholdBytes = 3000
****.channelNumber = 0**
****.numberOfChannels = 1**
**.basicBitrate = 6e6
****.retryLimit = 4**

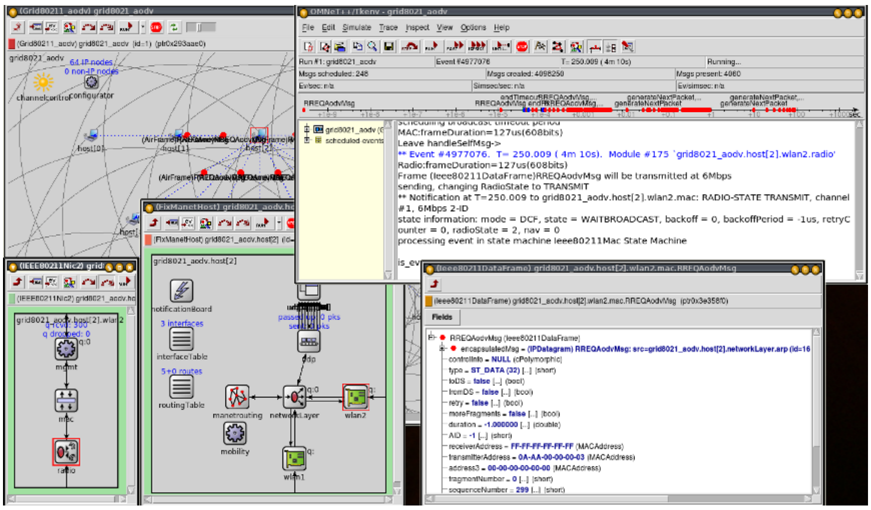
**.cwMinData = 15
**.cwMinBroadcast = 31
****.opMode = 'a' #802.11a**
**.slotTime = 9us #
**.AIFSN = 2 #DIFS

#radio settings
****.transmitterPower=30** ;[mW]
**.carrierFrequency=5.2E+9
**.thermalNoise=-95
****.sensitivity=-82**
**.pathLossAlpha=3.1;
**.snirThreshold = 4 # in dB
**.receiverAntennaGain = 1 ;simplificando
**.ht = 1 ;simplificando
**.hr = 1 ;simplificando
****.phyOpMode = 'a'**

channel physical parameters
*.channelcontrol.carrierFrequency = 5.2e+9
*.channelcontrol.pMax = 30.0 ;[mW]
***.channelcontrol.sat = -95**
*.channelcontrol.alpha = 12.5
*.channelcontrol.numChannels = 1
****.channelModel = 'r'** #r/a rayleigh/awgn
**.pathLossExponent = 3 ; //obstruct
**.shadowingVariance = 6 ; //segÃºn tablas...
**.shadowingNumberofSamples = 1000;
****.rician_factor = 5;**

[Run 1]
seed-0-mt = 34980117
seed-1-mt = 309550880
seed-2-mt = 430143272
seed-3-mt = 478383452

- Graphical interface



- Command-line interface
  - Simulation results:
    - Output vectors
      - Output vectors are time series data: values with timestamps

```
vector 2091  "grid8021_aodv.host[37].udpApp[0]"  "Received Packets"  1
2091   205.14 37
2091   205.14 0.00094136
2091   210.14 36
2091   210.14 0.00094341
2091   215.14 37
2091   215.14 0.00095139
vector 1972  "grid8021_aodv.host[29].udpApp[1]"  "Received Packets"  1
1972   215.14 37
1972   215.14 0.0014029
```

    - Scalar results
      - Watch parameters and extract statistics

```
"packets received by queue"       680
"packets dropped by queue"  0
"Contention Window.mean"    11.7777777778
"Contention Window.stddev"  9.77175416633
"Contention Window.min"     0
"Contention Window.max"     31
```

```
"Total received" 1435
"Total deleted" 0
"Total duplicated" 0
"Time receiving" 199.79511
"First packet" 300.13861307
"Last packet" 499.93372307
"Throughput" 7.18235796662
"Mean delay" 0.00100115579034
"Min delay" 0.000905070453769
"Max delay" 0.00519611617767
"Deviation delay" 0.000217544352437
```

```
"simulated time" 550.000213002
"Aodv totalSend " 88321
"Hello send"  68719
"Hello rec"   343935
"RREQ created" 30
"RREQ send" 7084
"RREQ rec" 15
"RREP created" 15
"RREP send"   66
"RREP rec"    15
"RERR created" 0
"RERR send"   0
"RERR rec"    0
"Total routes created" 15
"Total routes deleted" 0
"Mean Number of hops"  66
"Total ETT pairs send" 5763
"Total protocol Overhead in Bytes" 17267972
```


- By default, omnett++ uses a better physical model than ns-2
  - Cumulative SINR for carrier sensing and interference
- Random number generators based on Mersenne Twister RNG
  - period of 2^{19937}-1, independent seeds
  - Akaroa support: Multiple replications in parallel
- Mobility
  - Basic, BonnMotion, Turtle, Rectangle, Linear, ANSim, Ns2Motion, ConstSpeed, RandomWP, Null, Circle

- Some modifications…
  - 802.11a parameters
    - SINR and Carrier Sensing thresholds are based on IEEE standard
    - BER computation
  - Extensions: Fading and propagation models
    - Rayleigh, Ricean
    - Free space, Two-ray, Shadowing
  - Traffic differentiation and multipath routing
  - Working on multi-radio…

WCIM model

Analysis

WCIM
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- WCIM model:
  - Load is defined in terms of channel occupancy

$$CF^{ij}{}_{k} = \frac{FR_k}{BW_{ij,k}}$$

  - Contention in transmission: x1

$$CL_i = CN^i + \sum_{\forall m \in N^i{}_1} CN^m$$

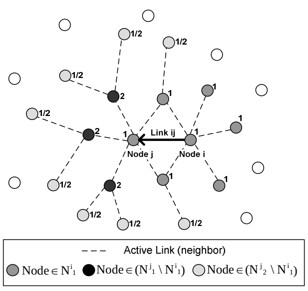
  - Hidden terminal interference in reception: x2

$$IL_{ij} = \sum_{\forall m \in (N^j{}_1 \setminus N^i{}_1)} 2 \times CN^m + \ldots$$

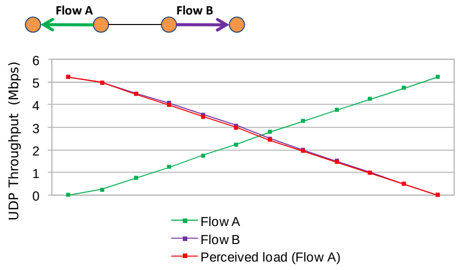
  - Two-hops interference in reception: x½

$$IL_{ij} = \ldots + \sum_{\forall m \in (N^j{}_2 \setminus N^i{}_1)} \frac{1}{2} \times CN^m$$

$$WCIM_{ij,k} = \frac{P_k}{BW_{ij,k} \times (1 - CL_i - IL_{ij})}$$

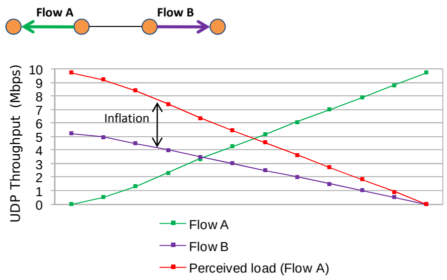


- Load and channel occupancy:
  - Example: Two nodes content for the channel:
    - Case 1: Both links are configured at 6 Mbps



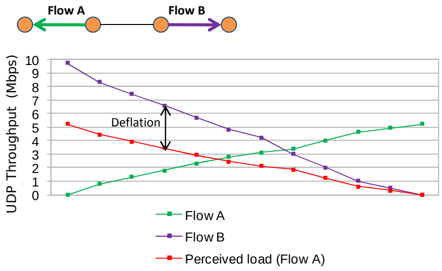
- The perceived load is the maximal achievable throughput of the Flow A (free channel) minus the throughput that the Flow A really achieves (channel occupied by Flow B)
- In this case, the load perceived by Flow A equals the real load of Flow B

- Load and channel occupancy:
  - Example: Two nodes content for the channel:
    - Case 2: Flow A is transmitted at 12 Mbps and Flow B at 6 Mbps



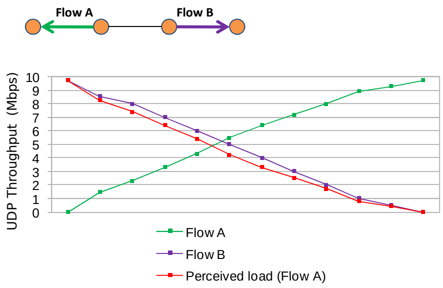
- In this case, the load perceived by Flow A is almost the double of the real load of Flow B
  - Since Flow B is transmitted at a lower transmission rate than Flow A, its packets occupy the channel for a longer time
  - Thus, the load perceived in the channel is higher than the real load (data bit rate) of Flow B

- Load and channel occupancy:
  - Example: Two nodes content for the channel:
    - Case 3: Flow A is transmitted at 6 Mbps and Flow B at 12 Mbps



- In this case, the load perceived by Flow A is almost the half of the load of Flow B
  - Since Flow B is transmitted at a lower transmission rate than Flow A, its packets occupy the channel for a shorter time
  - Thus, the load perceived is lower than the real load of Flow B

- Load and channel occupancy:
  - Example: Two nodes content for the channel:
    - Case 1: Both links are configured at 12 Mbps



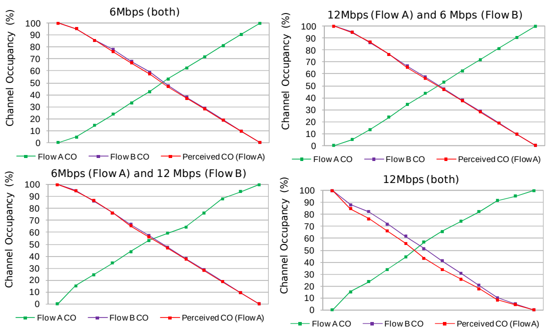
- Again, the load perceived by Flow A almost equals the load of Flow B, since both links are configured at the same transmission rate

- Load and channel occupancy:
  - Conclusions:
    - – In load-aware metrics, the load parameter should be defined in terms of channel occupancy
      - The load of the nodes is perceived differently according to the characteristics of the links
        - – For instance, a higher link bit rate leads to a lower channel occupancy
    - – Thus, the load parameter used by WCIM metric is defined in terms of channel occupancy
      - Percentage of the link bandwidth that occupies the load of a flow

$$CF^{ij}_{k} = \frac{FR_k}{BW_{ij,k}}$$

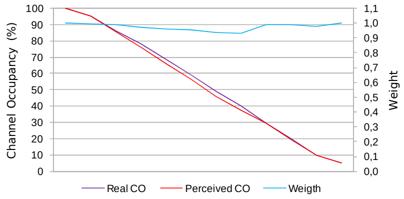
Channel occupancy of flow *k* through link *ij* (CF^{ij}_{k}); Data rate of flow *k* (FR_k); Bit rate of link *ij* ($BW_{ij,k}$)

- Load and channel occupancy:
  - Defining a load based on channel occupancy (CO), as WCIM does, previous results show the following relationship between real and perceived channel occupancy



- – Figures show that defining load in terms of channel occupancy leads to a better estimation of the real channel consumption of a contending node

- Contention in transmission:
  - Using the previous results, we can obtain an average weight between perceived CO and real CO in the case of two nodes contending in transmission



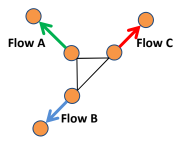
  - As waited, the figure shows that the weight (Perceived CO / Real CO) is near 1 in all cases (right horizontal axis)
  - Thus, the % of channel occupied by a contending node in transmission should be considered applying a weight of 1
    - WCIM:

Contention level in transmission: CL_i; Channel consumption of the transmitter: CN^i; Channel consumption of contending neighbors: $\sum_{\forall m \in N^i_1} CN^m$

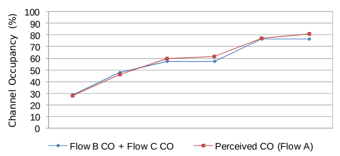
$$CL_i = CN^i + \sum_{\forall m \in N^i_1} CN^m$$

- Contention in transmission:
  - Considerations with several contending nodes:

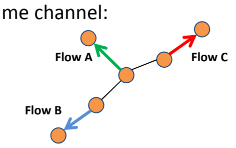
- If all the nodes do contend for the same channel:



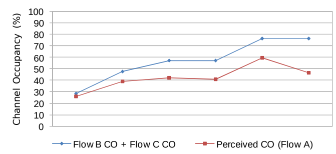
  - Only one node can transmit in a given time
  - Thus, the perceived channel occupancy will be similar to the sum of the channel occupancies of all the nodes
  - **Example:** Two contending nodes



- If some contending nodes do not contend for the same channel:



  - Some contending nodes can transmit simultaneously
  - Thus, the perceived channel occupancy will be less than the sum of the channel occupancies of all the nodes
  - **Example:** Two contending nodes

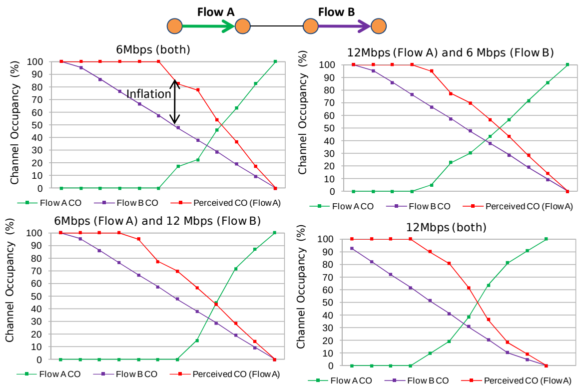


WCIM model
Analysis

- Contention in transmission:
  - Conclusions:
    - In the case of only one contending node, a weight of **1** estimates adequately its impact of its load on the channel occupancy
    - In the case of multiple contending nodes, the perceived channel occupancy depends on the relative position between contending nodes and the probability of simultaneous transmissions
      - Since these two parameters are difficult to consider at layer three (routing protocol), WCIM applies the **sum of channel occupancies**
        - It works correctly in the case of all the nodes contending for the same channel
        - It overestimates the impact of contention in the other cases (upper bound)

WCIM model
Analysis

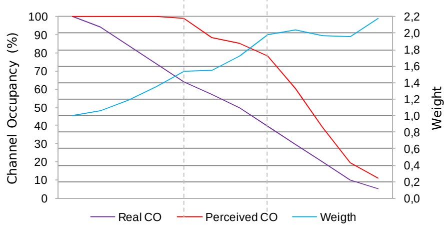
- Hidden Terminal in reception:
  - We consider a similar methodology to the previous analysis
    - But now, the transmitter of Flow B is a hidden terminal to the receiver of Flow A



- Figures show that in all the cases, the perceived CO by Flow A suffers a significant inflation compared to the real CO of Flow B

WCIM model
Analysis

- Hidden Terminal in reception:
  - Using the previous results, we can obtain an average weight between perceived CO and real CO in the case of a hidden terminal



– We can consider three differentiated zones:
  - Perceived CO = 100% - Weight between 1 and 1,5
    – The channel is totally occupied: *starvation*
  - Perceived CO > 75% - Weight between 1.6 and 2
    – The channel is almost full or very interfered: *high probability of collisions*
  - Perceived CO < 75 % - Weight around a value of 2
    – The channel is medium to low interfered: *less probability of collisions*

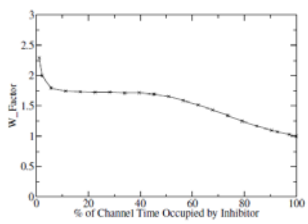
21

WCIM model
Analysis

- Hidden Terminal in reception:
  - Conclusions:

– We take an average **weight of 2** in order to estimate the impact of the load or channel occupancy of the hidden terminals

– Results are similar to [1]:
  - Experimental
  - Only one configuration is considered
    – Both nodes at 6 Mbps
  - Results lead to an inflation average of **1,7**



[1] A. Raniwala, P. De, S. Sharma, R. Krishnan, T. C. Chiueh "Globally fair radio resource allocation for wireless mesh networks", In 2009 IEEE International Symposium on Modeling, Analysis & Simulation of Computer and Telecommunication Systems (September 2009), pp. 1-10.

22

- Hidden Terminal in reception:
  - Conclusions:
    - As in the contending case, WCIM considers the sum of loads in the case of having several interfering hidden terminals
      - Again, the real impact depends on the relative position between hidden terminals and the probability of simultaneous transmissions
    - WCIM:

Interference level in reception — Channel consumption of the Hidden Terminals

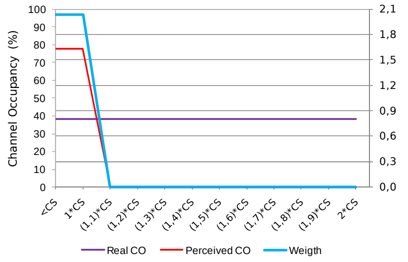
$$IL_{ij} = \sum_{\forall m \in (N^{j}_{1} \setminus N^{i}_{1})} 2 \times CN^{m} + \ldots$$

- Two-hops interference in reception:
  - The interference of distanced nodes (two-hops or further), depends on several parameters. For instance:
    - The relative distance between the sender, the receiver and the interferer
    - The number of interfering nodes and the probability of simultaneous transmissions
    - The modulation of the interfered reception
  - Analysis:

    - We vary the distance between Node 1 and Node 2
      - From a Hidden Terminal case (distance <= carrier sensing range (CS)) up to the two-hops neighborhood limit (distance >= 2xCS)
    - We also consider the number of interfering nodes (1 or 2) and the transmission bit rate (6 Mbps or 12 Mbps)
      - Additive interference
      - Robustness of the modulations

WCIM model
Analysis

- Two-hops interference in reception:
  - Case 1:
    - One interfering node, Flow A is transmitted at 6 Mbps

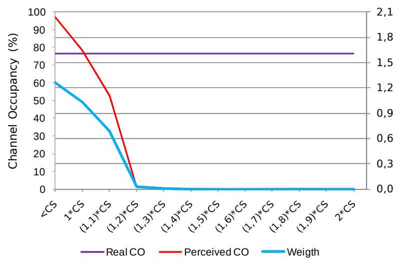


    - In this case, a two-hops neighbor only interferes in the limit of the CS range (1*CS)
      - Weight of 2
    - Since the transmission uses the lowest bit rate, it is robust to distanced interference

25

WCIM model
Analysis

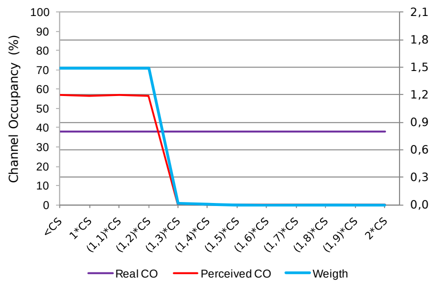
- Two-hops interference in reception:
  - Case 2:
    - Two interfering nodes, Flow A is transmitted at 6 Mbps



    - In this case, the additive interference causes an increment of the interference distance up to 1,1*CS
    - The weight between Real and Perceived CO also decreases due to simultaneous transmissions (additive interference)
      - Distance < 1,1*CS: Simultaneous transmissions decrease the % of channel time occupancy
      - Distance = 1,1*CS: Only simultaneous transmissions do interfere

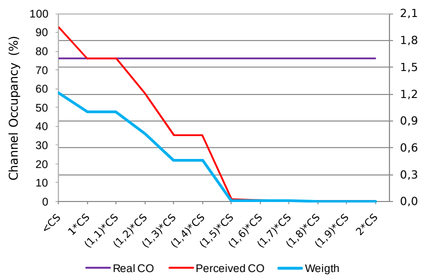
26

- Two-hops interference in reception:
  - Case 3:
    - One interfering node, Flow A is transmitted at 12 Mbps



    - Since the modulation is less robust, the distance of interference increases up to 1,2*CS regarding the 6 Mbps case
      - Weight of 1,5

- Two-hops interference in reception:
  - Case 4:
    - Two interfering nodes, Flow A is transmitted at 12 Mbps



    - Again, the additive interference of the two nodes causes the interference distance to grow up to 1,4*CS
    - Also the probability and impact of simultaneous transmissions cause the weight to decrease
      - Between 1,2 and 0,5

- Two-hops interference in reception:
  - Conclusions:
    - Very challenging to model
      - Depends on distance, modulation, additive interference, probability of simultaneous transmissions…
    - According to the results, the estimation of the interference of two-hops neighbors on the perceived channel occupancy should be:
      - Lower than the case of Hidden Terminals (weight of 2 in WCIM) and contenders in transmission (weight of 1 in WCIM)….
        - High distanced nodes do only interfere in cases of additive interference
        - The interference of Hidden Terminals also depend on distance in the case of active receptions, but they also can “capture” the channel of the receiver (it will discard any incoming receptions)
        - Any detected contending transmission will impact the channel occupancy, no matter of distance
      - …but it should be considered (weight higher than 0)
        - In some cases, it impacts significantly the perceived CO due to collisions

WCIM model
Analysis

- Two-hops interference in reception:
  - Conclusions:
    - Thus, intuitively and qualitatively, we choose a weight of ½ in order to model the interference of the two-hop neighbors of the receiver
      - **WCIM**:

Interference level in reception

Channel consumption of the Hidden Terminals

$$IL_{ij} = \ldots + \sum_{\forall m \in (N^j{}_2 \setminus N^i{}_1)} \frac{1}{2} \times CN^m$$