NetSim®

Accelerate Network R & D

Wireless Energy Harvesting for Internet of Things

Version 15.0

A Network Simulation & Emulation Software

By

TETCOS LLP

Software: NetSim Standard v15.0, Visual Studio 2022

Project Download Link:

https://github.com/NetSim-TETCOS/Wireless_Energy_Harvesting_for_IOT_v15.0/archive/refs/heads/main.zip

Follow the instructions specified in the following link to download and set up the Project in NetSim:

https://support.tetcos.com/en/support/solutions/articles/14000128666-downloading-and-setting-up-netsim-file-exchange-projects

1 Introduction to Energy Harvesting

Among various methods like vibration, light, and thermal energy extraction, wireless energy harvesting (WEH) has proven to be one of the most promising solutions due to its simplicity, ease of implementation, and wide availability. This technology trend is gaining attention as it offers a fundamental approach to extending the lifespan of batteries. While harvesting from environmental sources depends on the presence of the corresponding energy source, RF (radio frequency) energy harvesting provides unique advantages, being wireless and easily accessible from transmitted energy sources like TV/radio broadcasters, mobile base stations, and handheld radios. It's cost-effective and allows for compact implementations.

1.1 Components of a WEH-Enabled Sensor Device

A typical WEH-enabled sensor device comprises key components: an antenna, a transceiver, a wireless energy harvesting (WEH) unit, a power management unit (PMU), a sensor/processor unit, and optionally, an onboard battery.

1.2 Calculation of Harvested Power (P_H)

The available Harvested power (P_H) is determined by the Friis equation. It is directly proportional to Transmitted power (P_T), Path loss (P_L), Transmitter antenna gain (G_T), Receiver antenna gain (G_R), the Power conversion efficiency of the converter (PCE_H), and the square of the wavelength (λ), and is inversely proportional to the square of the communication distance (r) between the source and the device.

1.3 Energy Components and Distribution

The energy consumed by the device can be categorized into communication energy (listening, receiving, and transmitting) and computation energy (processing and sensing).

- Listening energy (E_{LS})
- Receiver energy (E_{RX})
- Transmitter energy (E_{TX})
- Processing energy (E_{PR})
- Sensing energy (E_{SN})

To capture the energy distribution among the aforementioned energy consumers, weighting coefficients, $\alpha_{LS} > \alpha_{TX} > \alpha_{RX} > \alpha_{PR} > \alpha_{SN}$, are assigned to them. The total average energy consumption $E_D = \alpha_{LS}E_{LS} + \alpha_{TX}E_{TX} + \alpha_{RX}E_{RX} + \alpha_{PR}E_{PR} + \alpha_{SN}E_{SN}$ is then calculated as the sum of the product of these coefficients and their respective energy components.

1.4 Battery Storage and Harvested Energy

The total energy stored in the device's battery is denoted as E_B. On the other hand, the available harvested energy per active-duty cycle is represented by E_H.

1.5 Topology Considerations

We assume constant energy consumption for the receiver, processor, and sensor. However, the energy consumption of the transmitter (E_{TX}) is directly proportional to the square of the distance (r_{ij}^2), where r_{ij} is the distance between the originating device (j) and the sink node (i), particularly in a ring topology or multihop topology. The harvested energy (E_H) is inversely proportional to r_{ij}^2 (here j is the sink node and $r_{ij} = r_{ji}$).

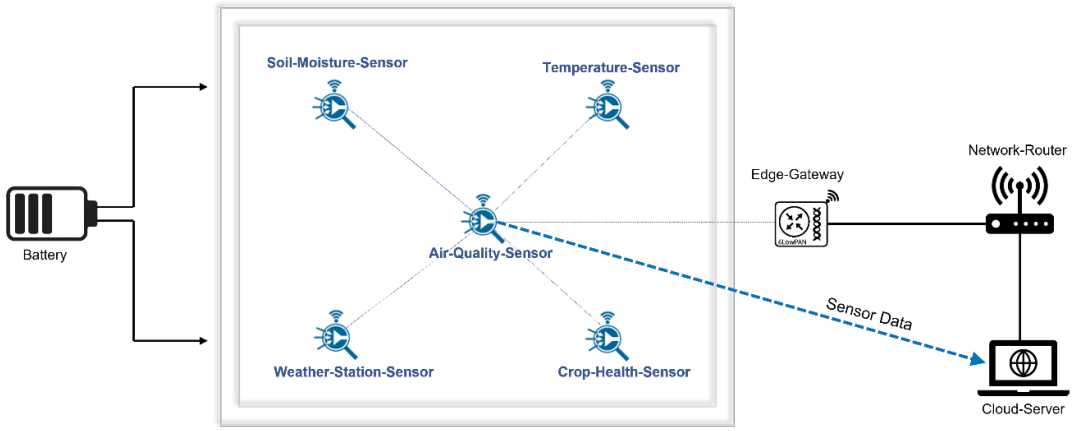

Figure 1-1: *Scenario for Smart agriculture system Without Energy harvesting.*

Figure 1-2: *Scenario for Smart agriculture system With Energy harvesting.*

2 Comparative Analysis

The `Energy_Harvesting_IOT_Workspace` includes sample network configuration files, namely `Without-energy-harvesting` and `With-energy-harvesting`, which are pre-saved.

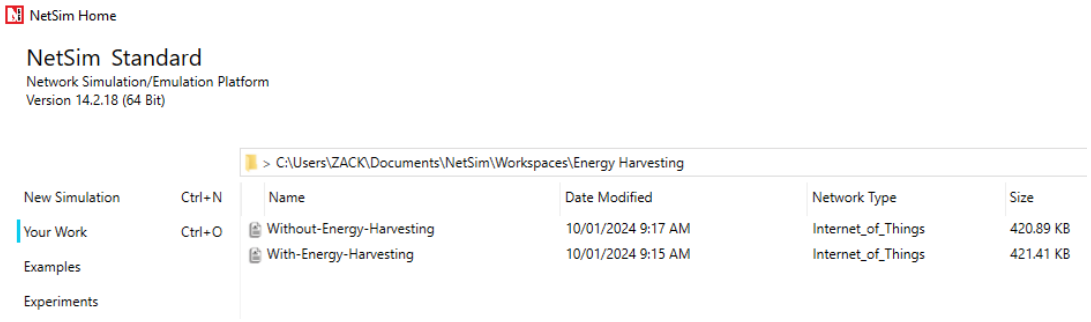

Figure 2-1: *Sample configuration files.*

We will now open the "Without-Energy-Harvesting" sample.

The network scenario consists of 16 sensors, a LoWPAN Gateway, a Router and a Wired Node as shown below.

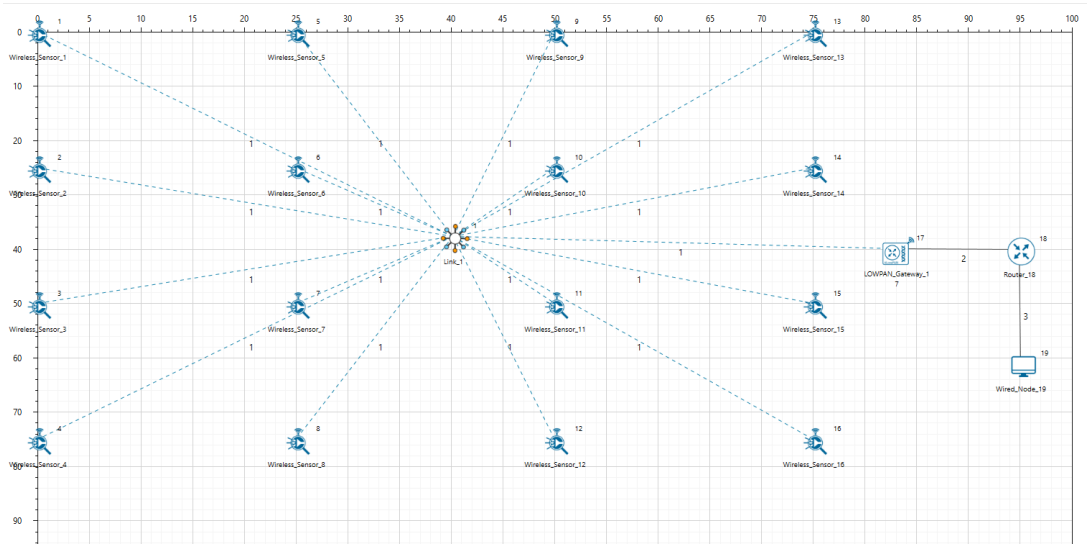

Figure 2-2: *Energy Harvesting Network Topology.*

Here, the Energy Harvesting parameter has been set to OFF in all Sensor nodes. To enable or disable the energy harvesting setting, users can navigate to Interface(ZigBee) → Physical layer → IEE802.15.4 → Power → Set Power source to Battery of the sensor nodes, as shown below.

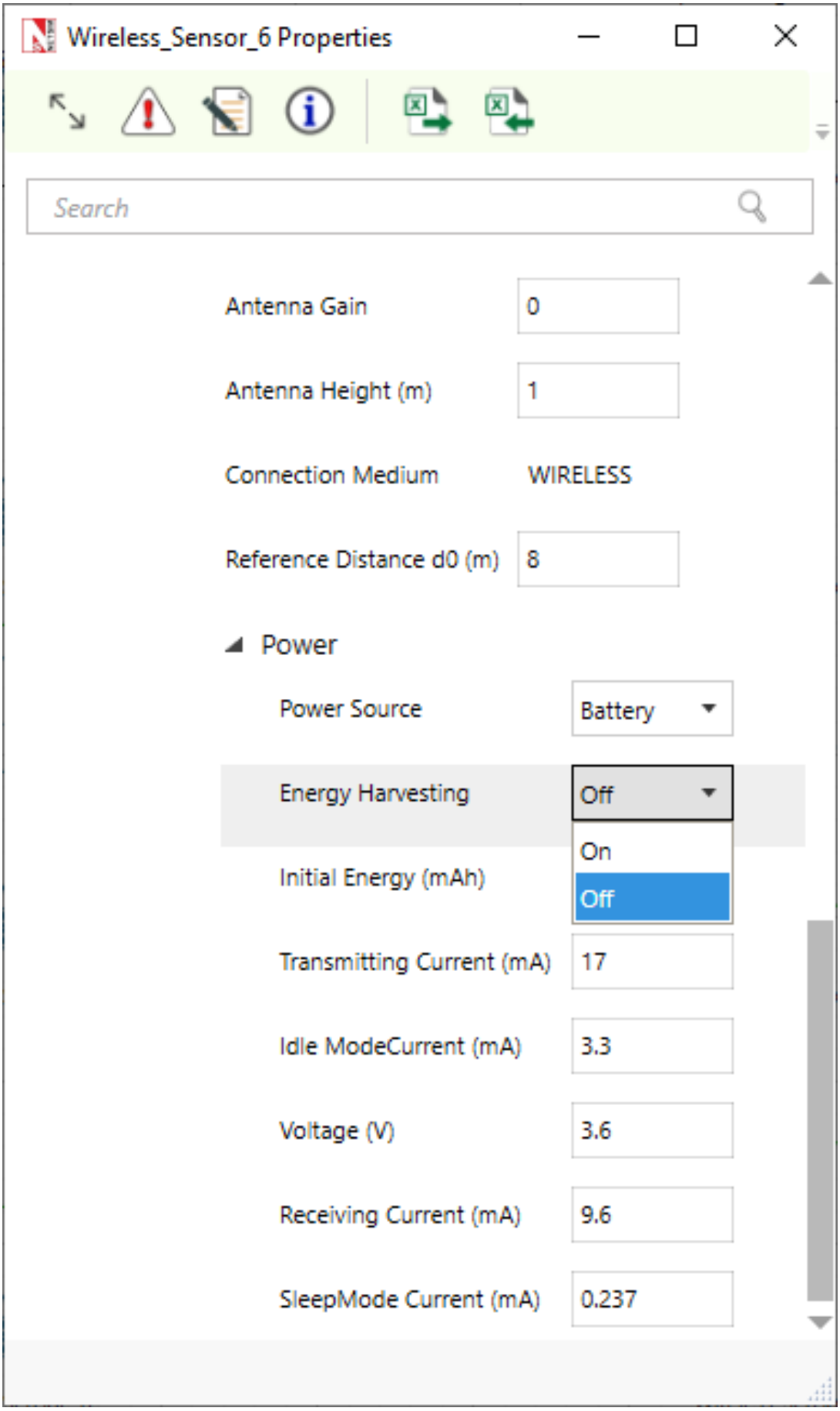

Figure 2-3: *Energy Harvesting parameter.*

Run Simulation for 100 seconds and save the simulation results.

3 Results and Discussion

Once the simulation is complete, the NetSim result dashboard will open. From there, navigate to the additional metrics section and select the Battery model under IEEE802.15.4_Metrics. This will display the Battery model table.

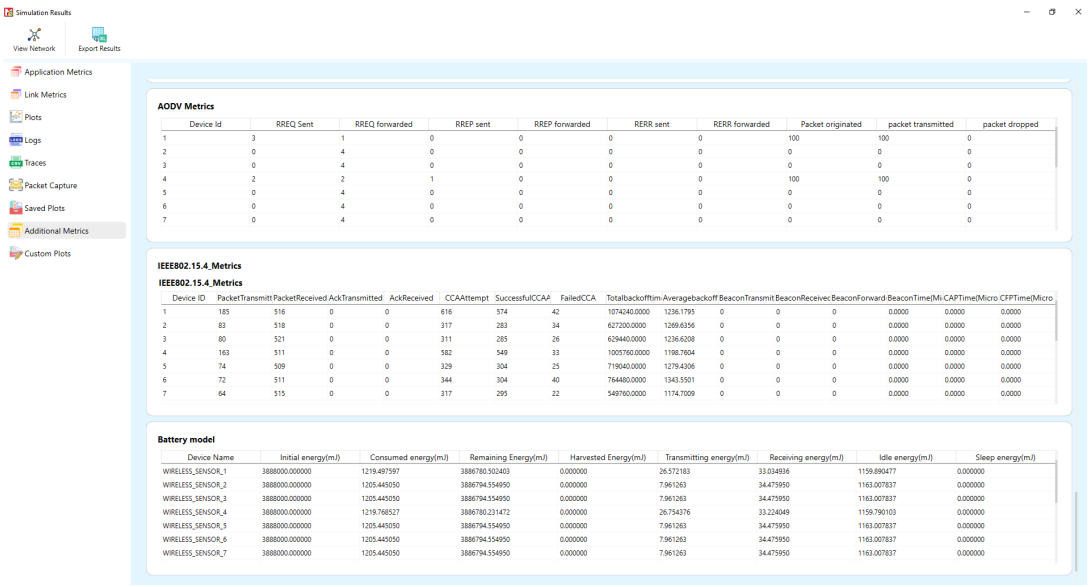

Figure 3-1: *Battery model table from NetSim result dashboard.*

Without Energy Harvesting:

In the Battery model table, you can observe the results for scenario without energy harvesting. This table provides detailed insights into the energy consumption of each sensor node.

Battery model

Device Name	Initial energy(mJ)	Consumed energy(mJ)	Remaining Energy(mJ)	Harvested Energy(mJ)	Transmitting energy(mJ)
WIRELESS_SENSOR_1	3888000.000000	1219.497597	3886780.502403	0.000000	26.572183
WIRELESS_SENSOR_2	3888000.000000	1205.445050	3886794.554950	0.000000	7.961263
WIRELESS_SENSOR_3	3888000.000000	1205.445050	3886794.554950	0.000000	7.961263
WIRELESS_SENSOR_4	3888000.000000	1219.768527	3886780.231472	0.000000	26.754376
WIRELESS_SENSOR_5	3888000.000000	1205.445050	3886794.554950	0.000000	7.961263
WIRELESS_SENSOR_6	3888000.000000	1205.445050	3886794.554950	0.000000	7.961263
WIRELESS_SENSOR_7	3888000.000000	1205.445050	3886794.554950	0.000000	7.961263

Figure 3-2: *Battery model table without energy harvesting.*

With Energy Harvesting:

Now, open and run the 'With-Energy-Harvesting' sample, where Energy Harvesting is enabled for all sensor nodes. Upon comparing the remaining energy levels with the "without-energy-harvesting" Scenario, you will observe increases in the working capability of sensors.

Battery model

Device Name	Initial energy(mJ)	Consumed energy(mJ)	Remaining Energy(mJ)	Harvested Energy(mJ)	Transmitting energy(mJ)
WIRELESS_SENSOR_1	3888000.000000	1219.497597	3886923.096872	142.594469	26.572183
WIRELESS_SENSOR_2	3888000.000000	1205.445050	3886937.149418	142.594469	7.961263
WIRELESS_SENSOR_3	3888000.000000	1205.445050	3886937.149418	142.594469	7.961263
WIRELESS_SENSOR_4	3888000.000000	1219.768527	3886922.825941	142.594469	26.754376
WIRELESS_SENSOR_5	3888000.000000	1205.445050	3886937.149418	142.594469	7.961263
WIRELESS_SENSOR_6	3888000.000000	1205.445050	3886937.149418	142.594469	7.961263
WIRELESS_SENSOR_7	3888000.000000	1205.445050	3886937.149418	142.594469	7.961263

Figure 3-3: *Battery Model table with energy harvesting.*

Simulations can be performed for different values of E_H Fraction which may vary as per the efficiency of the Energy Harvesting unit.

> You can observe slight variation in the remaining energy with and without energy harvesting as the simulation time is in seconds.

4 Appendix: NetSim Source Code Modifications

4.1 Changes to Battery Model.h within Battery Model project

```
/* We implemented the Battery Model*/

#ifndef _NETSIM_BATTERY_MODEL_H_
#define _NETSIM_BATTERY_MODEL_H_
#ifdef __cplusplus
extern "C" {
#endif

#ifndef _BATTERY_MODEL_CODE_
#pragma comment(lib,"BatteryModel.lib")
typedef void* ptrBATTERY;
#endif

_declspec(dllexport) ptrBATTERY battery_find(NETSIM_ID d,
NETSIM_ID in);
_declspec(dllexport) void battery_add_new_mode(ptrBATTERY battery, int mode, double
    current, char* heading);
_declspec(dllexport) ptrBATTERY battery_init_new(NETSIM_ID deviceId, NETSIM_ID
    interfaceId, double initialEnergy, double voltage, double dRechargingCurrent);

_declspec(dllexport) bool battery_set_mode(ptrBATTERY battery, int mode, double time);
_declspec(dllexport) void battery_animation();
_declspec(dllexport) void battery_metrics(PMETRICSWRITER metricsWriter);
_declspec(dllexport) double battery_get_remaining_energy(ptrBATTERY battery);
_declspec(dllexport) int battery_energy_harvesting(ptrBATTERY battery, double
    eh_energy);
_declspec(dllexport) double battery_get_consumed_energy(ptrBATTERY battery, int mode);

#ifdef __cplusplus
}
#endif
#endif //_NETSIM_BATTERY_MODEL_H_
```

4.2 Changes to double battery_get_remaining_energy(), Battery Model.c within Battery Model project

```
_declspec(dllexport) double battery_get_remaining_energy(ptrBATTERY battery)
{
return battery->remainingEnergy;
}
_declspec(dllexport) int battery_energy_harvesting(ptrBATTERY battery, double
    eh_energy)
{
double eh_energy_mJ = eh_energy * ((pstruEventDetails->dEventTime - battery->
    modeChangedTime) / 1000000);
battery->remainingEnergy += eh_energy_mJ;
}
```

4.3 Changes code to ChangeRadioState.c, within Zigbee project at the end of the file

```
#define EH_FRACTION 0.1
// EH_FRACTION is the fraction of the received signal energy that can be
// captured and harvested by the sensor.
int calculate_eh(NETSIM_ID dev1, NETSIM_ID dev2)
{
double rx_pwr = GET_RX_POWER_mw(dev1, dev2, pstruEventDetails->dEventTime);
double eh_energy = EH_FRACTION * rx_pwr;
ptrBATTERY battery = WSN_PHY(dev2)->battery;
if (battery)
battery_energy_harvesting(battery, eh_energy);
}
```

4.4 Changes code to int fn_NetSim_Zigbee_Run(), 802_15_4.c file, within Zigbee project

```
case UPDATE_MEDIUM:
{
double dtime=pstruEventDetails->dEventTime;
NETSIM_ID nLink_Id, nConnectionID, nConnectionPortID, nLoop;
NETSIM_ID nTransmitterID;
nTransmitterID = pstruEventDetails->nDeviceId;
ZIGBEE_CHANGERADIOSTATE(nTransmitterID, WSN_PHY(nTransmitterID)->nRadioState,
    RX_ON_IDLE);
if(WSN_PHY(nTransmitterID)->nRadioState != RX_OFF)
WSN_MAC(nTransmitterID)->nNodeStatus = IDLE;
nLink_Id = fn_NetSim_Stack_GetConnectedDevice(pstruEventDetails->nDeviceId,
    pstruEventDetails->nInterfaceId,&nConnectionID,&nConnectionPortID);
for(nLoop=1; nLoop<=NETWORK->ppstruNetSimLinks[nLink_Id-1]->puniDevList.pstruMP2MP.
    nConnectedDeviceCount; nLoop++)
{
NETSIM_ID ncon = NETWORK->ppstruNetSimLinks[nLink_Id-1]->puniDevList.pstruMP2MP.
    anDevIds[nLoop-1];
if(ncon != pstruEventDetails->nDeviceId)
{
calculate_eh(nTransmitterID, nLoop);
```

```
WSN_PHY(ncon)->dTotalReceivedPower -= GET_RX_POWER_mw(nTransmitterID,ncon,
    pstruEventDetails->dEventTime);
if(WSN_PHY(ncon)->dTotalReceivedPower < WSN_PHY(ncon)->dReceiverSensivity)
WSN_PHY(ncon)->dTotalReceivedPower = 0;
}
}
```

4.5 IEEE Reference Paper

Wireless Energy Harvesting for the Internet of Things
P. Kamalinejad, C. Mahapatra, Z. Sheng, S. Mirabbasi, V. C. M. Leung, Y. L. Guan
IEEE Communications Magazine, June 2015