Whitefield

Last-mile IoT simulation framework

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https://github.com/whitefield-framework/whitefield

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Background

It all started with a project: AMI network

Requirements: Scale to 1K nodes, roughly 10-12 hops

Mixed L2 network: 802.15.4 Sub-Ghz and NB-PLC

- How to check what is the achievable performance at that scale?
  - PDR, Convergence time, Repair time etc
  - Can the existing routing protocols implementations scale in LLNs?

AMI - Advanced Metering Infrastructure

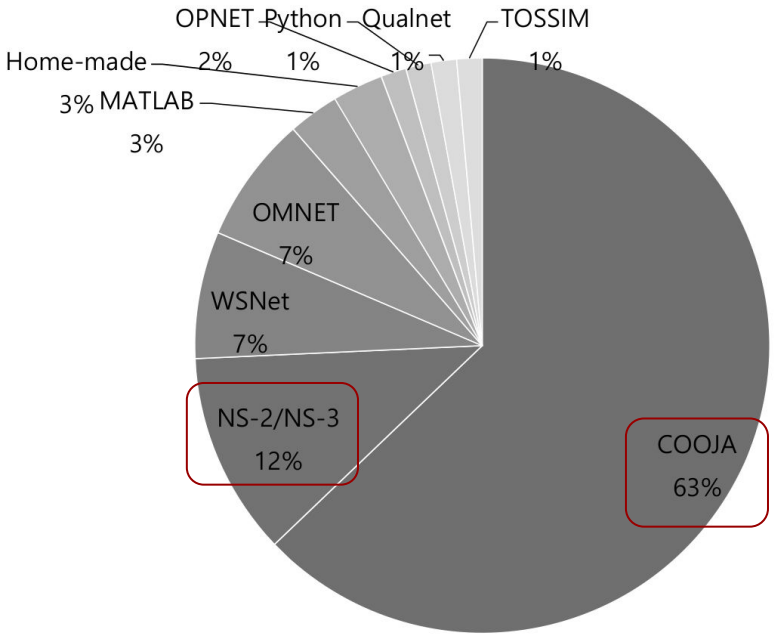
So, how to verify?

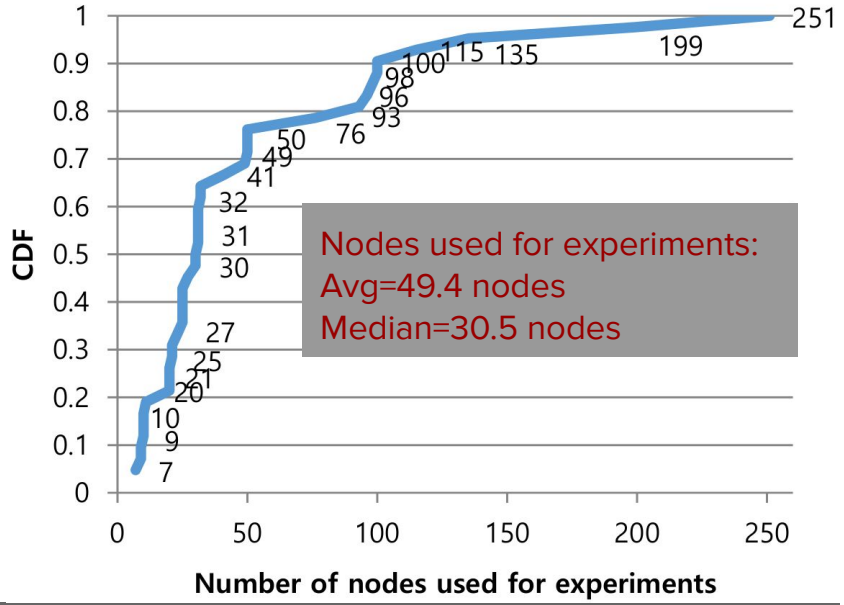
- Hardware testbed
  - Such as FIT IOT-Lab, Indriya2
  - Still not the same scale!
  - Difficult to handle frequent updates
  - Difficult to debug
  - Good for late-stage verification but not ok for early-stage experimentation
- Existing simulation frameworks
  - So we tried Cooja, but...
    - Scalability issues
    - How to handle PLC links?
    - For 802.15.4, the results looked too good to be true!
  - So for realistic simulation we decided to try NS3, but...
    - Cannot plugin real world stacks as is

But what about...

- NS3 DCE (Direct Code Execution)
  - Allows executing native linux apps inside NS3 without changing code
  - However, DCE depends on specific Linux kernel primitives and is not easy to setup
    - Checkout GSoC2018_DCE_Upgrade
- Using NS3 TAP Bridge model
  - Not scalable
  - Depends on the native app using TAP interface

What everyone seems to be doing?





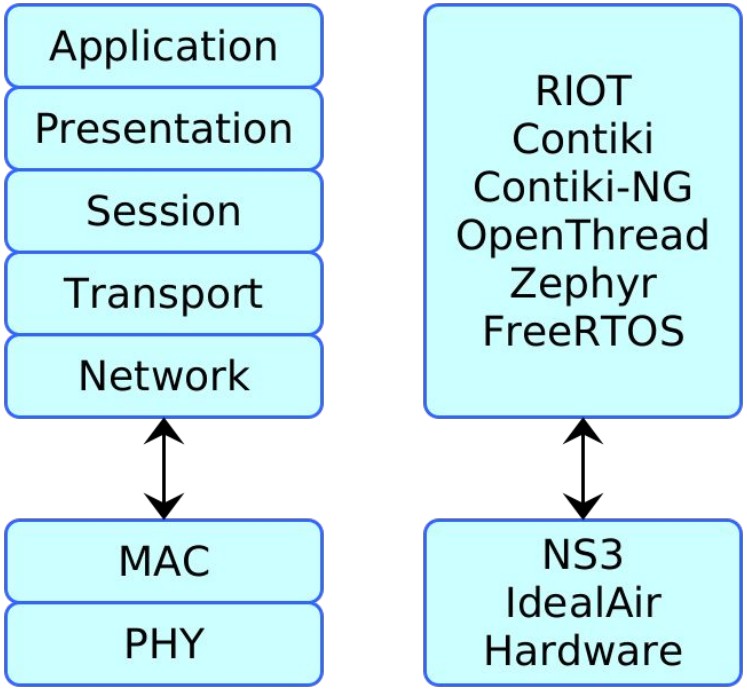
Ref: Challenging the IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL): A Survey, Hyung-Sin Kim et.al. 2017

With Low Power comes great responsibility...

- Overall, what we found was...
  - Untrustworthy results from most of the papers
  - Experiments conducted in limited scope
    - Extremely difficult to reproduce
    - Comparative analysis was difficult
  - Very less numbers of nodes experimented with
- Bad idea to depend on Cooja for experiments depending on
  - Realistic propagation loss and delay models
  - Asymmetric wireless models

Introducing Whitefield...

- Started during IETF-96
- Design goals
  - Integrate proven simulation models with real-world network stacks
  - Scale to thousands of nodes
- Real-world stacks
  - RIOT, Contiki, Contiki-NG
  - OpenThread (in progress)
- Proven simulation models
  - NS3-Lrwpan (802.15.4)
  - NS3-PLC (Power Line Comm)

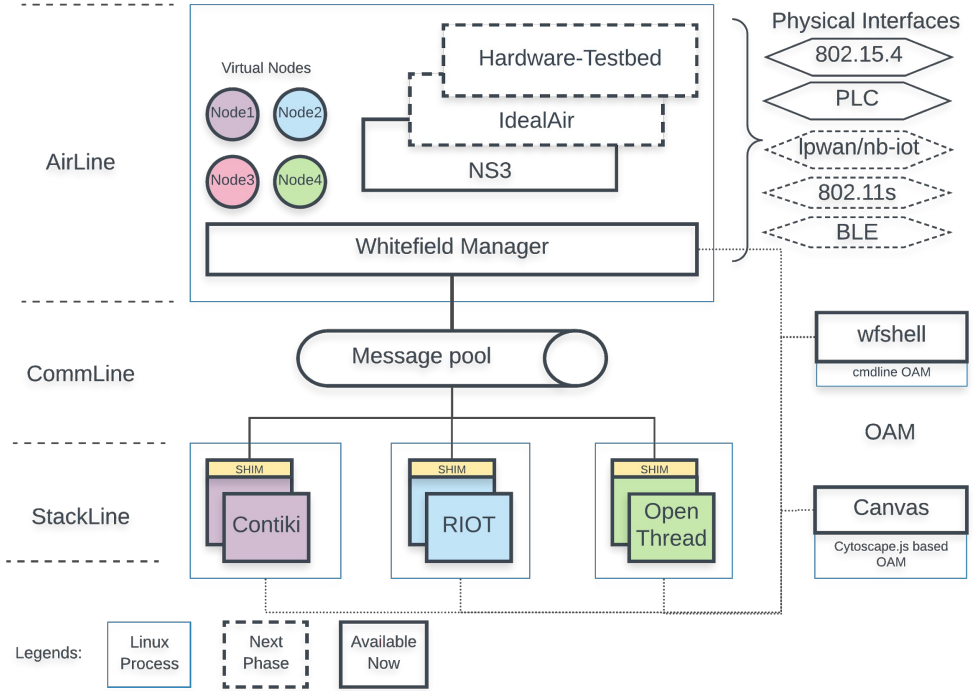


What we wanted

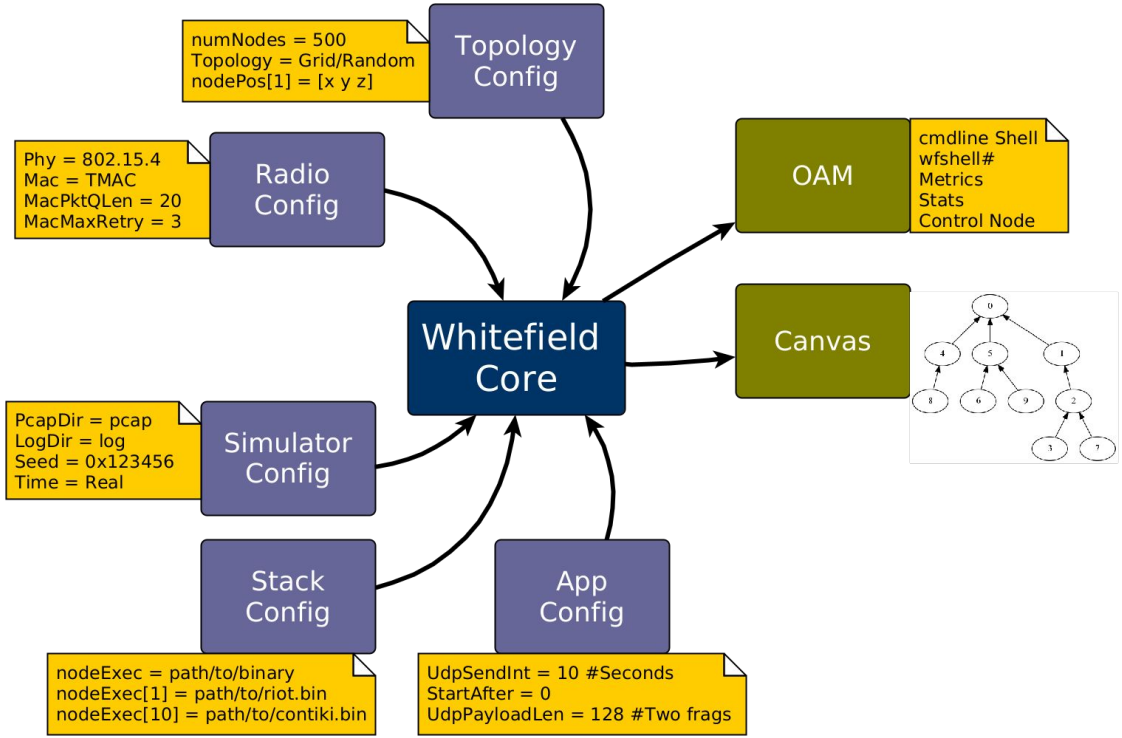
- Performance benchmarking
- Reproducible data
- Realistic conditions
  - Propagation loss/delay models
  - Realistic wireless or wireline characteristics
- Ability to use real-world IoT network stacks
  - Ability to also mix real-world stacks in same deployment
- Experiment without limitation
  - Ability to freely add debug info
- Shareable scenario config

High Level Design

- RIOT/... implements a Whitefield platform/driver
- Whitefield handles message inter-play between RIOT and NS3
- Whitefield supports
  - Multiple phy interfaces
  - Simulates mixed L2 network with 802.15.4 and PLC today



Whitefield config



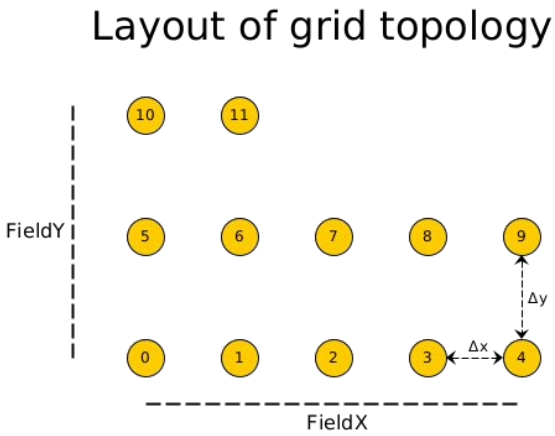
What is supported today?

- Interfaces
  - 802.15.4
  - PLC
    - Narrowband & G3
    - Different PLC cable types
  - Multiple interfaces
- Propagation Loss Models
  - LogDistance(def) / Friis / FixedRSS / Matrix / Random / Range / TreeLogDistance / TwoRayGround
- Propagation Delay Models
  - ConstantSpeed(def) / Random
- TxPower configuration per node
- Ability to configure individual attributes of these models

```
PHY=plc # lowpan/plc .. default lowpan

# References:
# https://github.com/ns3-plc-module/plc
# www.ece.ubc.ca/~lampe/plc/

# ----[PLC Cable]----
# AL3x95XLPE
# NYCY70SM35
# NAYY50SE
# MV_Overhead
# NAYY150SE <default>
plc_cable=NAYY150SE # Def cable type used if no cable is specified
#plc_tx_psd=1e-8  # -50dBm/Hz

#plc_mac=ARQ    #Possible options: ARQ(def), HARQ

# ----[PLC Spectrum Model]----
# narrowband = GetSpectrumModel(0, 500e3, 5)
# G3 = G3 Standard spectrum model
# <default> = GetSpectrumModel(0, 10e6, 100)
plc_spectrum_model=narrowband

# Set Outlet Impedance
# plc_outlet_impedance[0]=50.5

# NOT-USED ANYMORE plc_interface[0]=rx #tx,rx,both(def),none

# PLC Link format
# plc_link[src_node]=dst_node,cabletype
plc_link[0]=1
plc_link[1]=2
plc_link[2]=3
plc_link[4]=0,NAYY50SE
plc_link[5]=1,NAYY50SE
plc_link[6]=2,NAYY50SE
plc_link[7]=3,NAYY50SE
```

What is supported today?

- Topology
  - Grid
  - Random Rectangle
  - Specify node positions individually in meters
- Mobility Models
  - RandomWalk2D / RandomWaypoint
  - Ability to change specific node's position at runtime using OAM command



Δx = fieldX / gridWidth
Δy = fieldY / (number of rows)
Number of rows = ceil(gridWidth/numOfNodes)

Example config:
---
numOfNodes = 12
fieldX = 200 #meters
fieldY = 200 #meters
topologyType = grid
gridWidth = 5

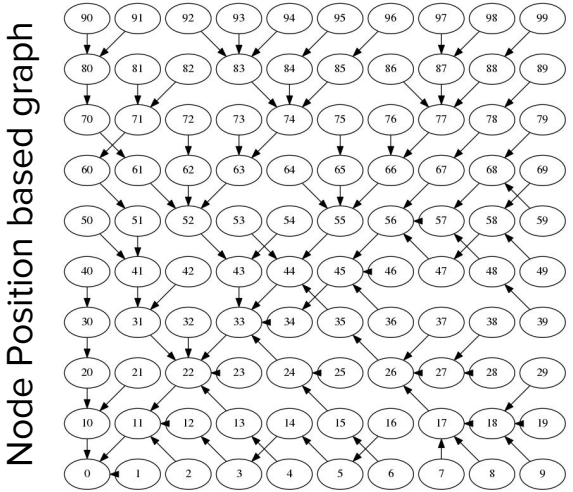
Thus,
Δx = 200/5 = 40m
Number of rows =ceil(12/5) = 3
Δy = 200/3 = 66m

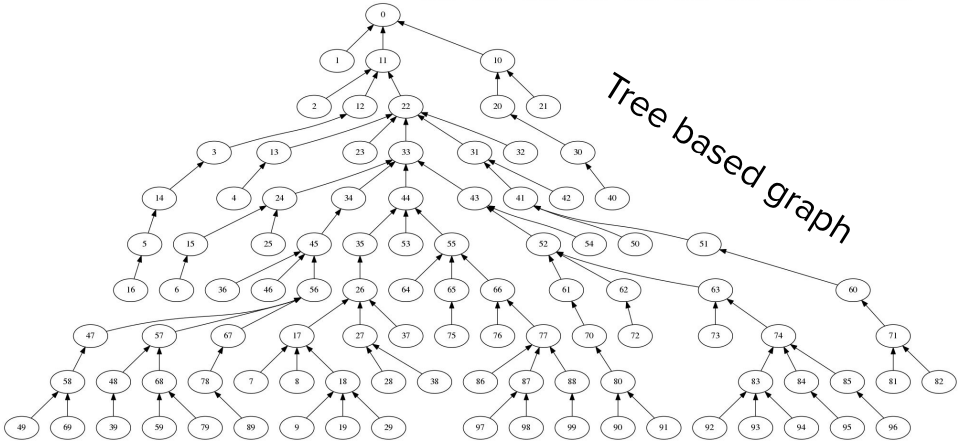
What is supported today?

- Stacklines:
  - RIOT
  - Contiki
  - Contiki-NG
- Ability to mix multiple stacks in same deployment
- To be supported in near future
  - OpenThread (partially completed, in-progress)
  - Zephyr (todo)
  - FreeRTOS (todo)
  - Plug-n-play model for supporting future stacks

What is supported today?

- Diagnostics & Monitoring
  - Logs & Pcaps on per node basis
  - Automated generation of stats/graphs
- Visualization
  - Position or tree based graph
  - Cytoscape.js based runtime visualization (alpha-stage)
- OAM
  - Whitefield shell
    - Stats
    - Control nodes
    - Whitefield start/stop/monitor





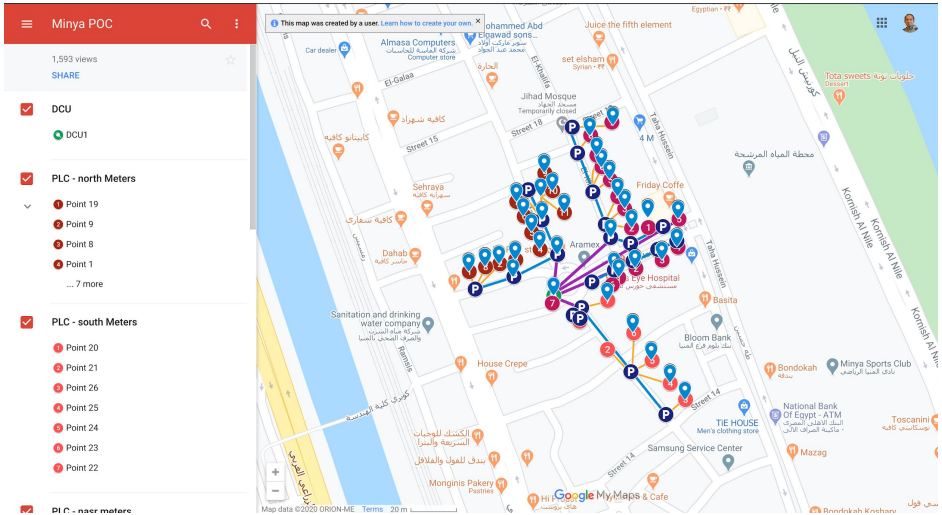
All this at scale...

Tested for 1200 nodes on Dell PowerEdge

Easily handles 500 nodes on general laptops

Work done using Whitefield

- Used it for AMI network verification
- draft-ietf-roll-rpl-observations
  - Observations of using RPL at scale
  - Could interop RIOT/Contiki at large scale for first time
- draft-ietf-roll-efficient-npdao
  - Optimized route invalidation for RPL
- draft-ietf-lwig-nbr-mgmt-policy
- Draft-ietf-6lo-minimal-fragment



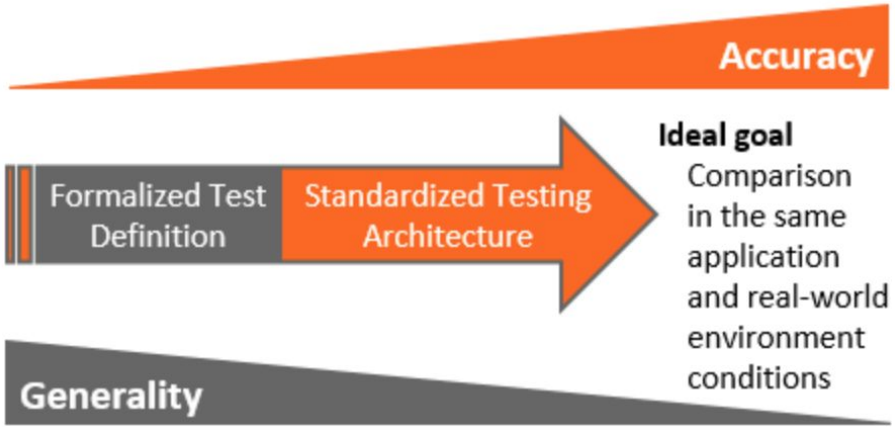
Immediate work items

- Plug-n-play mode
  - Allow users to submit RIOT/Contiki bins compiled in their native env to Whitefield
  - Whitefield will wrap the fork of bin and will override platform/rf driver primitives
- OpenThread support
- Support for energy modelling
- Supporting renode.io for hardware emulation
- Support for LoRAWAN and NB-IoT interfaces

A word about IoTBench

IoT BENCH

Raise the bar in the quality of experimental data, and provide researchers and engineers in both academia and industry with an objective view of the strengths and weaknesses among existing protocols.



To summarize

- With low-power comes great responsibility
  - Not easy to verify algorithms/protocols efficiency in LLNs at scale
- Dearth of tooling which can do realistic simulation at scale
  - while integrating with real-world stacks
  - Extremely difficult to do realistic tests with mixed L2 networks
- Currently, we do not have common benchmarks to rely on
  - In part due to the fact that tooling is insufficient
- Whitefield hopes to bridge these gaps

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