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Implementation of Brute Force Algorithm for Topology Optimisation of Wireless Networks

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***Abstract*—The paper discusses the topology optimisation of wireless networks using a brute force algorithm. In order to reduce the computational complexity of the algorithm the multi-thread application has been implemented to conduct the optimisation procedure. The efficiency of the algorithm was verified using an example task where topology of a wireless network has been optimised under various criteria.**

***Keywords*—topology optimisation; wireless networks; parallel computing; brute force algorithm**

I. Introduction

Dramatic increase of various electronic services in the past decade requires continuous and reliable access to network resources. The continuous access to electronic services for mobile subscribers is provided by wireless technologies to transfer data between electronic devices by air. Wireless networks use means of radio communication to ensure access of mobile devises to the network applications.

The main benefits of wireless networks comparing to conventional wired networks are: mobility, productivity, simplicity of deployment and operation, scalability and low cost [1]. The main types of wireless networks are shown in Fig.1 and can be considered as following:

- Personal Area Network (WPAN), connects devices located in the close area of a person;
- Local Area Metwork (WLAN), provides communication of two and more devices using an access points to the Internet;
- Metropolitan Area Network (MAN), connects several local networks;
- Wide Area Network (WWAN), covers a large area such as cities and nearby towns and settlements.

The high demand in wireless networks installation and expansion is explained by both intensive growth of the number of mobile clients and simplicity of the wireless access provision [2]. Technologies of wireless networks are widely used in many areas – mobile communication, voice messages, navigation systems, remote control, travel and entertainments, business, home networks, corporative management etc.

Wireless networks can provide access to services in places, where wire connection cannot be established, for example, city parks and stadiums. Expansion of a network coverage area can be done by simple installation of additional points of access. It has been noted that modern wireless networks form completely new professional environment for certain categories of citizens. For example, wireless network technologies are extremely crucial for medical doctors and students. It provides doctors with opportunity to monitor the patients condition continuously whereas students have access to learning materials at whatever time they chose. Classification of wireless networks can be also based on the services they provide. For example, GSM networks are the basis for digital mobile telephony widely used in the world.

II. Mobile Networks

Wireless networks are the main instrument of network access for telecommunication services. Computational resources of modern mobile devices such as smart phones are sufficient for processing of resource-intensive network applications [3]. All modern mobile devices are equipped with Wi-Fi adapters and GPS receivers. However, communications in mobile system require existence of base stations (Fig. 2) [4].

A. Wireless Sensor Networks

Wireless Sensor Networks (WSN) can use several options of wireless technologies including IEEE 802.11 WLANs, Bluetooth and RFID. Currently, the majority of WSN devices are equipped by low power transmitters providing data transfer in the area of a radius 10-50 m at a speed up to 300 Kbps. Wireless sensors consist of several basic components – sensors, modules of data processing and send-receive devices.

The field of WSN application is very wide. They can be used in monitoring of ecological and technological parameters of the environment and control objects. A very promising area of implementation of WSNs is medicine. Fig. 3 shows a scenario of WSNs application in medical field where information about patient condition is transmitted and collected irrespectively of the location. Data from the sensitive elements connected to the patient body are sent to the medical centres via Internet. However, such medical applications of WSNs require provision of information security in case of

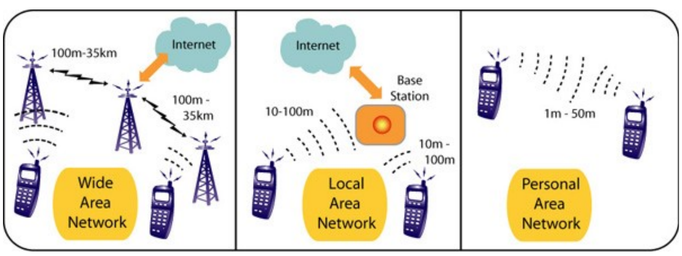

Fig. 1. Types of wireless networks [5].

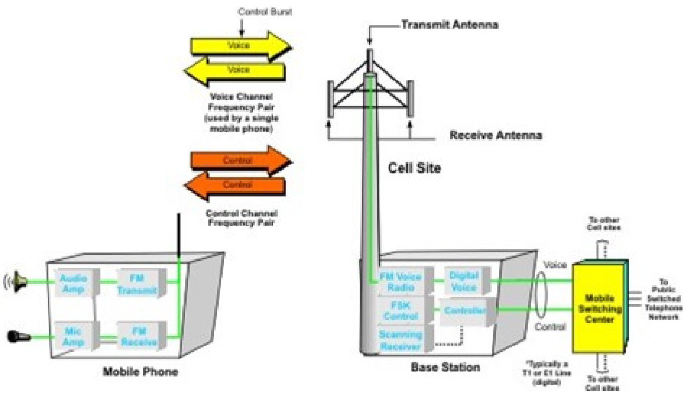

Fig. 2. Data transmission in mobile networks [4].

data transfer through open channels of communication. Security of communication, identification and control of access to personal data are main issue of implementation of mobile network technologies in medical applications [6].

B. Wireless Mesh Network

Wireless Mesh Network (WMN) is a communication network comprising of the nodes forming a grid topology. It is also a form of the wireless ad hoc network. WMNs consist of clients, routers and gateways. Clients of the network could be laptops, cell phones and other wireless devices. Routers provide transport of data between clients and gateways connected to Internet (Fig. 4). WMNs use various wireless technologies including standards 802.11, 802.15, 802.16. A WMN allows people living in remote areas and small businesses working in rural districts to connect their networks to Internet.

III. Design of Topology of Wireless Network

Wireless network has to provide various and often contradictory demands of potential users. Therefore, design of wireless networks includes optimisation procedures to develop an optimum solution. For example, the network parameters which could be used for optimisation are

- the number of network users and their status;
- types of mobile and stationary devices served by the network;
- what services are necessary for users;
- what speed of connection is necessary for their support;
- need to access of spatial localization of the zone.

The quality of services provided by a wireless network depends on characteristics of installed equipment and its topology allocation. The topology of a wireless network comprises of three fragments: (1) connection point-point (point-to-point) used for connection of two networks, for example, the point-to-point bridge connecting two buildings with different networks; (2) connection a point-multipoint (point-to-multipoint) used for connection of three and more LAN, for example, of several settlements; (3) peer-to-peer network – independent local area network without protect infrastructure where all stations are connected directly to each other.

At the stage of network topology design the spatial distribution of the elements forming the communication channels is developed. In fact, it is an optimisation task requiring introduction of various optimisation algorithms. The cost of equipment, the level of security of access to network services, uniformity of a signal in the coverage area can be used as criteria of optimisation at this stage of the network design.

IV. Synthesis of Optimal Network Topology

Optimisation problems are often solved using genetic algorithms, one of the strongest heuristics based on the principle of natural selection. The genetic algorithm can be applied for the solution of optimisation tasks which can not be resolved under standard optimisation algorithms, particularly when criterion function is not continuous, not differentiable, stochastic or significantly nonlinear. Bhondekar et al. [7] suggested application of the modified genetic algorithm for design of WSN where the proposed algorithm finds the optimal location of the nodes in the network providing

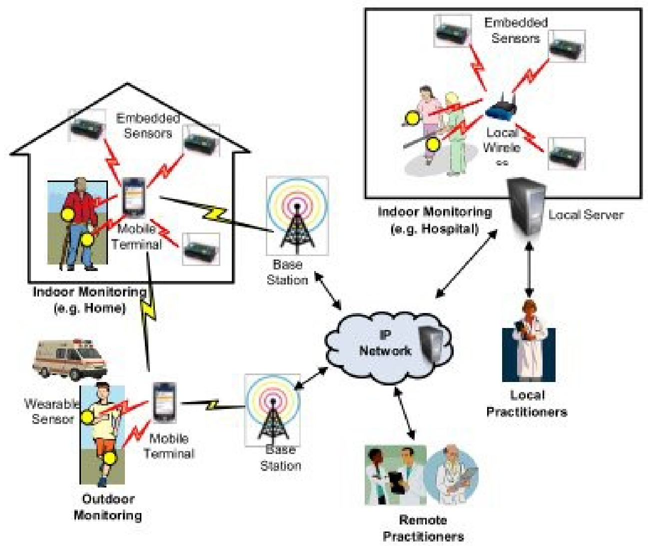

Fig. 3. Medical WSN [6].

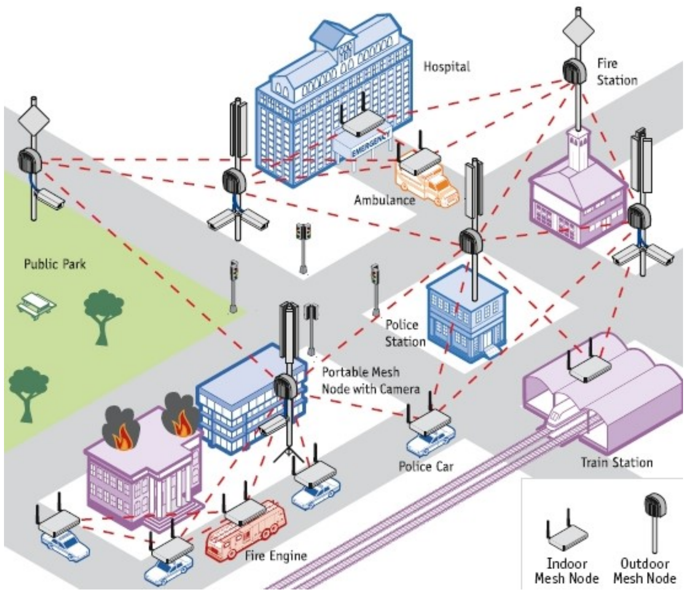

Fig. 4. Wireless Mesh Network [8].

minimisation of the energy consumed by sensors for wireless transmission. However, a significant drawback of genetic algorithms is related to complexity and difficulties of their adaptation to a task to be solved.

Alternative methods of optimisation are based on search algorithms (brute force algorithms). However, these methods require significant computational resources and have not been widely used in the past. Recent improvement in computers such as multi-core processors and accelerators expanded the area of implementation of brute force algorithms and made it applicable for topology optimisation tasks. In order to use a brute force algorithm the task of network topology should be formulated as following:

1. Let $\{\mathbf{A}_N\}$ be a finite set of network elements which can be allocated in possible positions $\{\mathbf{P}_K\}$. In practice, the number of positions is much larger than the number of elements: $K >> N$.

2. Find the distribution of elements $\{\mathbf{A}_N\}$ at the positions $\{\mathbf{P}_K\}$ providing an extrema of some functional F. The solution of the problem is the N-dimensional vector $\{\mathbf{D}_N\}$ which elements belong to $\{\mathbf{P}_K\}$:

$$\{D_n\} = (P_1, ..., P_n), P_i \in \{P_k\}, \forall i = 1, n \quad (1)$$

$$F(D_n) \rightarrow \min(\max) \quad (2)$$

Generally, the task can be multi-criteria. This formulation of the problem allows for introduction of brute force algorithm as a multi-threaded application.

V. Results of Experiment

This section discusses an example of implementation of a brute force algorithm for topology optimisation of a wireless network. The minimum cost of the equipment and the access level of peoples to network services have been used as optima criteria. Input parameters of the task are given in the form of the list of coordinates of settlements and their population.

Design of optimum topology of the wireless network can be considered as a task of determination of the such spatial location of channel-forming active elements which provides an extrema of some functional. The accuracy of the functional value depends on the accuracy of antennas coordinates defined by the step of coordinate grid. It is noted that the criteria chosen for the optimisation contradict each other. Therefore, the problem of the topology design is the tasks of multi-criteria optimisation. The main criterion used in the task is the access level to services of the network whereas the cost of the decision is the secondary criterion. It must be noted that this work focuses on computing aspects of the task rather than on formation of criteria functions. The use of the fixed step of coordinate grid forms a limited number of positions on the plane that transfers the task into class of discrete optimisation problems [9, 10].

The brute force algorithm analyses all decisions and makes chose which option is corresponding to extrema of the criteria function. It also provides invariance of algorithm to criteria functions. The computational complexity of the algorithm is be defined as $O(K^N)$. Calculation of functional value F is performed at each point of (K^N)-dimensional space of decisions.

TABLE I. Location of Settlements

Town	X	Y	Population
1	4.2	17.7	500
2	4.5	17.8	100
3	4.9	17.5	100
4	3.8	4.5	500
5	4.1	4.7	100
6	3.5	4.6	100
7	16.5	3.8	500
8	16.7	3.6	100
9	16.3	4.2	100

It is suggested that two types of antennas are used in the example task as channel equipment: (1) directional antenna (DA, type A) having the range of communication $R_{\max} = 8$ km and cost of £300, (2) unidirectional antenna (ODA, type B) having the range of communication of $R_{\max} = 4$ km and cost of £100 (conditional parameters). The coordinates of the centres of settlements and the number of people living there are given in Table I. The required decision may contain up to three antennas – $N = 3$. The number of positions, which can be occupied by antennas, is set by a number of grid steps of M_x and M_y. It is assumed that these numbers are equal $M_x = M_y = M$. Therefore the number of antenna positions equals to $K = M^2$. Fig. 5 shows a graphical representation of the task.

Let's define criteria of an optimal topology arrangement of antennas where the following parameters should be taken into account:

1. Power of communication signal P is inversely proportional to the square of distance R between receiver and the antenna:

$$P_i(R) = P_i^0 / R^2 \quad (3)$$

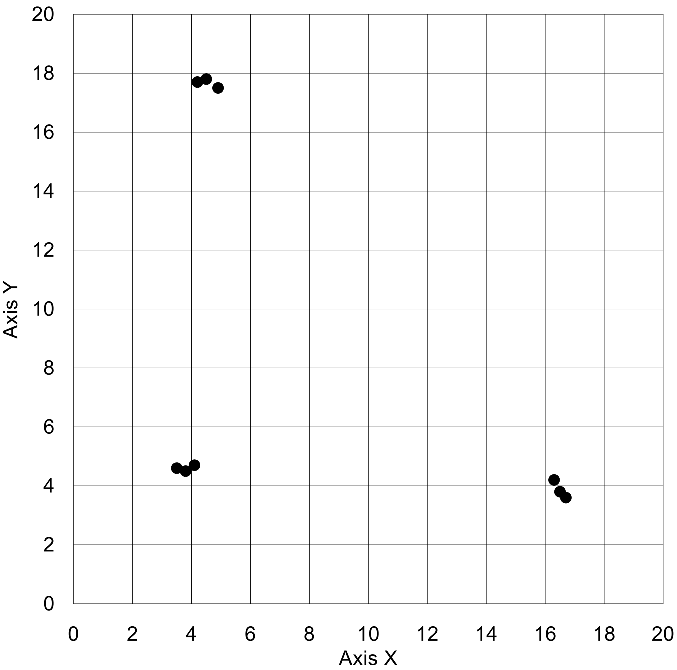

Fig. 5. Location of settlements.

2. The transfer of information between network nodes is possible under the following condition:

$$R \le R_{\max} \quad (4)$$

3. The set of settlements are characterised by location coordinates (X, Y) and the number of inhabitants (C):

$$T_i = \left(X_i, Y_i, C_i\right) \quad (5)$$

Therefore the optimisation criteria can be formulated as following:

1. Maximising the number of the residents provided with access to the network:

$$F_1 = \sum_{i=1}^{L} D(T_i) \times C_i \to \max \quad (6)$$

where $D(T_i) = 1$ if the distance between the city T_i and any antenna is less than $R_{\max}$.

2. Maximising the number of the residents provided with the high level of the antenna signal:

$$F_2 = \sum_{i=1}^{L} P\left(T_i\right) \times C_i \to \max \quad (7)$$

3. Maximising the minimum level of the network signal accepted by residents:

$$F_3 = \min\left(P\left(T_i\right)\right), \forall i = 1, L \to \max \quad (8)$$

The assessment of option of antenna placement is formed by the city having the minimum value of signal level F_3.

4. Minimising the cost of the channel-forming equipment:

$$F_4 = \sum_{i=1}^{n} \cos \mathrm{t}\left(A_i\right) \to \min \quad (9)$$

In this case the chosen option has the minimum cost of the equipment. In the given example the criterion F_4 is auxiliary.

It has been found that the computational complexity of calculation of all these criteria is approximately the same. The results of the solution are show in Table II. It can be seen that the algorithm develops the best solution by criterion F_1 for two antennas. The criterion F_2 takes into account the level of the signal accepted in the city. That converts one antenna network task into a problem of mass centre of distributed mass where the characteristic of mass objects appears the number of inhabitants of the settlements. For the given coordinates of settlements (Table I), the coordinates of optimum position of the antenna are $X = 8.2$ and $Y = 8.7$. However the problem of network topology design is much complicate. This is why the algorithm has to be on a parallel platform.

The accelerator Intel Xeon Phi has been used as a hardware platform for implementation of the multi-threaded parallel application. Intel Xeon Phi is the multi-core coprocessor with shared memory. Model 7120P used in experiments contains 61 cores [9]. It is possible to use two models of interaction with the coprocessor:

- offload: the application is run on the host and parts of code are unloaded on the coprocessor;
- native: the code is carried out initially on the coprocessor, all code and dependences have to be loaded on the device. This method was used in the experiments.

TABLE II. RESULTS OF THE APPLICATION (SEQUENTIAL IMPLEMENTATION)

N	M	F1			F2		
		ODA	DA	Time (sec)	ODA	DA	Time (sec)
1	10	700	1400	0.006	491.5	736.7	0.007
	20			0.007	667.7	738.6	0.008
	30			0.008	685.4	739.1	0.011
	40			0.011	682.1	738.7	0.013
	50			0.012	676.3	738.9	0.014
	60			0.014	683.2	739.1	0.016
	70			0.017	685.4	738.9	0.019
	80			0.019	684.7	739.0	0.022
	90			0.022	685.4	739.2	0.024
	100			0.023	685.1	739.0	0.028
2	10	1300	2000	0.03	529.3	758.9	0.03
	20	1400	2100	0.36	712.9	867.6	0.393
	30			1.79	733.3	896.5	1.88
	40			5.62	731.6	899.2	5.86
	50			13.67	726.7	897.5	14.20
	60			28.38	734.2	906.9	29.55
	70			52.47	736.9	911.0	54.87
	80			89.69	736.6	911.8	93.14
	90			143.24	737.7	913.7	149.48
	100			218.28	737.6	914.3	228.64

Each core has own L1 and L2 caches, operates at the frequency of 1.2 GHz and can support up to 4 threads with cyclic switching. All coprocessor can support 244 hardware parallel flows reaching on computation with double precision of performance 1.2 TFLOPS. On each kernel L2 cache has the size 512 KB whereas L1 cache has the size 32 KB for instructions and data. L2 cache provides the mode of coherence and allows for data transmition between the cores through an internal token ring network. The maximum bandwidth of the memory bus makes 352 GB/s. Localisation of data and use of vector transactions determine the efficiency of use of the coprocessor. Intel Advanced Vector Extensions (AVX) technology provides execution at 16 operations of unary or 8 operations of double precision for clock period. Multithreaded application was developed and debugged in the environment of Intel Parallel Studio 2015 in language C ++ with use of OpenMP library. Load distribution between cores of the accelerator was carried out by means of the function "*omp parallel for*".

The results of are presented in Table III and Fig. 6. Table III demonstrates the time of the task solution whereas Fig. 6 shows scalability of the application. In case of low computing load (M = 10) parallel implementation of algorithm is inefficient because the overhead costs for creation of multiple cores exceed the prize on time of calculations. However, when M ≥ 20 parallel algorithm possesses almost linear scalability.

VI. CONCLUSION

The paper discusses the topology optimisation of wireless networks using brute force algorithm. The example task has been solved to verify the propose approach. It is confirmed that the brute force algorithm can be effectively used for determination the location of wireless networks channel-forming elements. Algorithm is invariant in relation to criteria

TABLE III. Results of the Application on Xeon Phi
(N = 3, Criterion F_1)

M	Cores	Time (sec)	M	Cores	Time (sec)
10	5	0.2327	30	5	162.71
	10	0.1332		10	78.22
	15	0.1085		15	52.15
	20	0.0898		20	41.01
	25	0.0842		25	35.04
	30	0.0956		30	26.12
	35	0.0865		35	25.09
	40	0.0922		40	22.32
	45	0.0921		45	19.49
	50	0.0834		50	17.35
	55	0.0909		55	16.77
	60	0.0907		60	14.53
20	5	13.91	40	5	972.4
	10	6.87		10	449.13
	15	4.70		15	311.16
	20	3.46		20	231.11
	25	2.91		25	200.42
	30	2.49		30	154.99
	35	2.19		35	138.82
	40	1.91		40	122.23
	45	1.65		45	106.27
	50	1.62		50	101.41
	55	1.50		55	86.56
	60	1.34		60	85.99
50	5	3381.03			
	10	1714.13			
	15	1161.62			
	20	915.38			
	25	695.94			
	30	575.67			
	35	508.83			
	40	433.48			
	45	384.66			
	50	351.03			
	55	318.32			
	60	305.77			

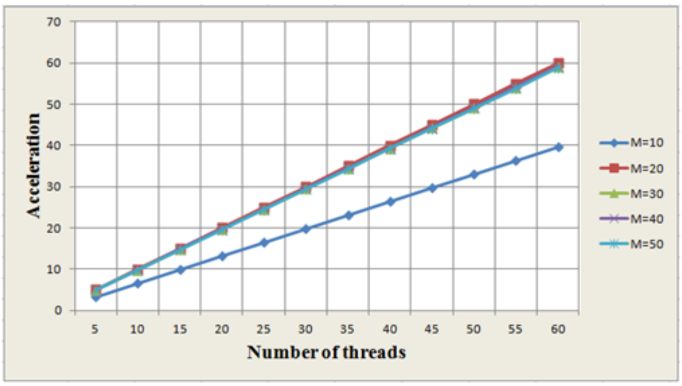

Fig. 6. Scalability of the application.

functions that allows the optimisation purposes to be changed without essential reorganisation of the application. Implementation of brute force algorithm for resolving of the optimisation task allows all exiting solution to be found. A drawback of the method is a high computational complexity. At small values of parameters M and N the problem can be solved using a powerful workstation, however at bigger values of the parameters require to used a multi-threaded realisation of the algorithm.

As for further work, the task of the network topology design can be simplified to reduce computational complexity by the fragmentation of the topology. In this case the decision will be obtained as a set of local optimum variants of topologies.

References

[1] N. Kaur, and S. Monga, “Comparisons of wired and wireless networks: A review,” *International Journal of Advanced Engineering Technology*, vol. 5, no. 2, pp. 34-35, April-June 2014.

[2] I.A. Shourbaji, “An overview of wireless local area network (WLAN),” *International Journal of Computer Science and Information Security*, vol. 11, no. 2, pp. 46-53, March 2013.

[3] Wei Li, and Xiuli Chao, “Modeling and performance evaluation of a cellular mobile network,” *IEEE/ACM Trans. on Networking*, vol. 12, no. 1, pp. 131-145, Feb. 2004.

[4] L. Harte, and D. Bowler, *Introduction to Mobile Telephone Systems: 1G, 2G, 2.5G, and 3G Wireless Technologies and Services*. Fuquay-Varina, N.C.: Alphos Pub., 2004.

[5] *Wireless Networks*. (2012, Jan. 26). [Online]. Available: http://www.e-cartouche.ch/content_reg/cartouche/LBSbasics/en/html/LBSBasicsU4_learningObject3.html

[6] G.S. Quirino, A.R.L. Ribeiro, and E.D. Moreno, “Asymmetric encryption in wireless sensor networks,” in *Wireless Sensor Networks - Technology and Protocols*, M.A. Matin, Ed. Rijeka, Croatia: InTech, 2012, pp. 219-232.

[7] A.P Bhondekar, V. Renu, M. Singla, C. Ghanshyam, and P. Kapur, “Genetic algorithm based node placement methodology for wireless sensor networks,” in *Proc. Int. MultiConference of Engineers and Computer Scientists IMECS 2009*, Hong Kong, March 18-20, 2009, vol. 1, pp. 106-112.

[8] *Firetide*. (2010, July 10). [Online]. Available: http://firetide.com/uploadedImages/Solutions/publicsafety_diag.jpg

[9] S. Lupin, Aye Min Thike, Hein Tun, and O. Kostrova, “Topology optimisation of wireless internet infrastructure,” in *Proc. IEEE NW Russia Young Researchers in Electrical and Electronic Engineering Conf.*, St. Petersburg, Russia, Feb. 2-3, 2016, pp. 362-364.

[10] Y.G. Evtushenko, and M.A. Posypkin, “Nonuniform covering method as applied to multicriteria optimization problems with guaranteed accuracy,” *Computational Mathematics and Mathematical Physics*, vol. 53, no. 2, pp. 144-157, Feb. 2013.

[11] S. Cepeda. (2012, Nov. 12). *Optimization and Performance Tuning for Intel Xeon Phi Coprocessors, Part 2: Understanding and Using Hardware Events*. [Online]. Intel developer zone. Available: https://software.intel.com/en-us/articles/optimization-and-performance-tuning-for-intel-xeon-phi-coprocessors-part-2-understanding