

# Developing Dual-Surveillance Based Vehicle Security Management with Generalized Honeycomb Tori

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*Abstract— After the 9/11 event, terrorist attacks related to vehicles cannot be overlooked. In some critical areas, security should be concerned from the context of streets or vehicle movement. Moreover, issues related to reliable/real-time operations, such as fault-tolerance, sight-line-obstruction, are getting more attention in contemporary terrorism background and/or vulnerable outdoor/ transportation environments. Therefore, we propose dual-surveillance and distributed-intelligence based SCADA (supervisory control and data acquisition) networks modeled from the Generalized Honeycomb Tori -i.e.,  $GHT(m,n,0)$  and  $GHT(m,n,n/2)$ , which are proved 1-edge hamiltonian and hamiltonian laceable if  $n \geq 4$ ;  $1_p$ -hamiltonia, if  $n \geq 6$  or  $m=2, n \geq 4$ , where  $m$  and  $n$  can be specified as a node matrix in an infrastructure-path or a road. Such networks are schemed for reducing sight-line-obstruction, and have optimal-degree and both nodes' and links' fault tolerance. Moreover, an integrated hamiltonian GHT-SCADA network is proposed for area's vehicle management by hamiltonian laceability in order to facilitate both security and maintenance operations.*

**Keywords:** Fault tolerance, Intelligent networks, SCADA systems, Transportation

## 1.0 Introduction

In this paper, we introduce basic terms related to generalized honeycomb tori first, then we discuss their applications in vehicle security, which is considered a serious issue for the urgent counter-terrorism appeal. In the latest symposium [12], we have discussed the application of GHT networks on parking structures, or on single-building level. In this symposium, by further research results of the hamiltonian *laceability* of the aforementioned networks, the compound network of GHT networks for vehicle security management in a critical area is discussed.

### 1.1 Definition

Usually, computer and communication networks are represented by graphs where nodes represent processors and edges represent links between processors. In this paper, we follow the graph representation in [2]. Let  $G = (V, E)$  be a graph if  $V$  is a finite set and  $E$  is a subset of  $\{(a, b) | (a, b) \text{ is an unordered pair of } V\}$ . We say that  $V$  is the *node set* and  $E$  is the *edge set* of  $G$ . Two nodes  $a$  and  $b$  are *adjacent* if  $(a, b) \in E$ . A *path* is a sequence of nodes such that two consecutive nodes are adjacent. A path is delimited by  $[x_0, x_1, x_2, \dots, x_{n-1}]$ . A path is called a *hamiltonian path* if its nodes are distinct and span  $V$ . A *cycle* is a path of at least three nodes such that the first node is the same as the last node. A cycle is called a *hamiltonian cycle* if its nodes are distinct except for the first node and the last node and if they span  $V$ . A graph is called *hamiltonian* if it has a hamiltonian cycle. A *bipartite graph*  $G = (V, E)$  is a graph such that  $V = A \cup B$  and  $E$  is the set:  $\{(a, b) | a \in A \text{ and } b \in B\}$ ; if  $G - F$  remains hamiltonian for any  $F = \{a, b\}$  with  $a \in A$  and  $b \in B$ , then  $G$  is  $1_p$ -*hamiltonian*. A graph  $G$  is *1-edge hamiltonian* if  $G - e$  is hamiltonian for any  $e \in E$ ; moreover, if there is a hamiltonian path between any pair of nodes  $\{c, d\}$  with  $c \in A$  and  $d \in B$ , then the bipartite graph  $G$  is *hamiltonian laceable*.

The generalized honeycomb torus is defined as the following. Assume that  $m$  and  $n$  are positive integers where  $n$  is even. Let  $d$  be any integer such that  $(m-d)$  is an even number. The *generalized honeycomb torus*,  $GHT(m,n,d)$  (Figure 1)

is the graph with the node set  $\{(i,j) | 0 \leq i < m, 0 \leq j < n\}$  such that  $(i,j)$  and  $(k,l)$  are adjacent if they satisfy one of the following conditions: (1).  $i=k$  and  $j = l \pm 1 \pmod{n}$ ; (2).  $j=l$  and  $k=i-1$  if  $i+j$  is even; and (3).  $i=0, k=m-1$ , and  $l=j+d \pmod{n}$  if  $j$  is even.

When  $d=0$ ,  $GHT(m,n,0)$  can be called *honeycomb rectangular torus*,  $HReT(m,n)$ , where  $m$  and  $n$  are positive even integers [3, 4].  $HReT(m,n)$  is the graph with the node set  $\{(i,j) | 0 \leq i < m, 0 \leq j < n\}$  such that  $(i,j)$  and  $(k,l)$  are adjacent if they satisfy one of the following conditions: (1).  $i=k$  and  $j = l \pm 1 \pmod{n}$ ; and (2).  $j=l$  and  $k=i-1 \pmod{m}$  if  $i+j$  is even.

It is proved that  $GHT(m, n, 0)$  or  $HReT(m,n)$  is *1-edge hamiltonian* if  $n \geq 4$ ;  $1_p$ -hamiltonian if  $n \geq 6$  or  $m=2, n \geq 4$  [4], and when  $m$  and  $n$  are positive integers with  $n$  and  $m-n/2$  being even,  $GHT(m, n, n/2)$  is proved *1-edge hamiltonian* if  $n \geq 4$ ;  $1_p$ -hamiltonian if  $n \geq 6$  or  $m=2, n \geq 4$  [3, 11]. Thus, the fault-tolerance we are engaged in is systematically based. Moreover, such properties are suggestively applied for parking structures and critical infrastructure-paths, such as artery roads, tunnels or critical paths in critical areas.

Furthermore, both  $GHT(m, n, 0)$  and  $GHT(m, n, n/2)$  are hamiltonian laceable if  $n \geq 4$  [10]. Two hamiltonian laceable bipartite graphs can flexibly form a compound bipartite hamiltonian cycle by respectively connecting the bipartite end-nodes of the hamiltonian path of each graph. Recursively, such a compound bipartite hamiltonian cycle can be joined naturally with another hamiltonian laceable graph to form again a new compound hamiltonian cycle. Therefore, all connected infrastructure-paths, which are configured with proposed dual-surveillance based GHT-SCADA networks, can get an integrated large-scale hamiltonian order capable of efficient/effective security and maintenance operations for area/general control. The total system can be flexibly zoned according to specific tasks.

## 1.2 Distributing Intelligent SCADA Networks for Convincing Security Management of Vehicles

Disaster sensitivities, including sabotage or terrorism, should be planned for critical infrastructures nowadays. For example, on February 18, 2003, a sabotage-fire occurred at a subway station at Daegu, R. Korea, and then a train entered [14]; many people's deaths were essentially due to lack of proper operation mechanism (joongangdaily. joins. com/200302/19). Moreover, an incident can consequently cause an infrastructure-path out of order physically and economically for months or even years after the damages; hence, considering proper operating network is very important for disaster sensitive critical infrastructure-paths.

Although efficient communication is demanded, proactive detection/computing analysis can be more demanding for security promotion in critical infrastructure-paths. For example, on June 4, 2005, a fire was initiated by the fuel leak of a tire truck in the 12.9-kilometer-long Frejus tunnel. Apparently, this disaster can be prevented/reduced because the driver "saw smoke pour into the right side of his car" and then safely escaped from the tunnel (www. geo-earth. com/forums).

Dual-surveillance, similar to the human-beings' two eyes, can help good detection in 3D real environment; for explanation, it is impossible to watch both sides of any vehicle or target by one camera or a set of cameras installed only in the middle section of the road. Therefore, establishing a sharp-3D-vision and real-time SCADA network for integrative operations in critical infrastructure-paths is essential; such a network needs to be a distributed-intelligence configuration, which can offer convincing detection and control.

Nevertheless, a critical infrastructure-path still can encounter unexpected failures, even with a well checked operation management. Hence, it is worthwhile to devise a SCADA network with a systematically proved fault-tolerance mechanism for proper operating management in a disaster sensitive infrastructure. Moreover, it is hoped that this operation management can also be featured with systematically checking or maintenance to reduce the possibility of failures in the network.

Mathematically, networks are composed of nodes and links. A node is essentially a processor or one set of processors; a link is essentially the wire connecting two nodes. Moreover, the number of links connecting a node is called the *degree*. The degree of the first node and the last node of a linear network is one, and the degree of a ring network is regularly two. Hence, the ring configuration can support operation even if a single link is broken. Thus, ring networks may traditionally be adopted for reliable infrastructure systems instead of linear networks. However, it is vulnerable as far as nodes' fault-tolerance is concerned; hence, the dual-node configuration is ideal for dealing with nodes' fault-tolerance.

At present, the CCTV (closed circuit television) is used as an effective, efficient, and reliable detection tool for proactive protection or adaptive monitoring in the contemporary disaster-sensitive critical infrastructure-paths [1,6,13,16]; hence, using CCTVs and other detectors or sensors, which may be adaptively grouped in the nodes, is recommended in our SCADA network prototypes for detecting traffic, incidents, and related data in infrastructures.

Besides, just as human beings' two eyes can provide more integral information for cognition, the installment of the CCTV in pairs can more convincingly monitor 3D space from different viewpoints and is often suggested in security designs [5,7,9,12]; therefore, establishing the network of dual-nodes is considered in this paper for having efficient/effective surveillance as well as nodes' fault tolerance.

## 2.0 Configuration

### 2.1 Prototyping Dual-Surveillance Based SCADA Networks with Optimal-Degree

Lesser degree can generally help network economy [15]. However, the degree of the ring network being two cannot ideally fit the degree requirement of a network of dual-nodes. Traffic information surveyed or analyzed by a node generally will be sent to the next node along with the traffic lane for logical processing and continual management. Therefore, the dual-nodes, similar to two eyes, which cooperate with each other, send the image information directly to the following required processing units as the single node does in conventional SCADA networks.

Hence, an extra link is demanded for dual-nodes, along with a forward node and a backward node; therefore, the minimum degree of the dual-surveillance based SCADA network should be three. Degree being three can have the benefit of direct information transmission especially from the view of executing checking or maintenance. In application, the dual partner logically has some similar attributes, for example, almost the same visual distance for potential targets; hence, the dual partners can be arranged basically in the same cross-section of the critical infrastructure-path.

In terms of the ring, which is generally used for basically concerning the fault-tolerance of a SCADA network, a double-ring network may be directly considered for the proposed dual-node scheme since it can easily use just three degrees to configure two rings of dual nodes, which can be intentionally differentiated by either black color or white color and linked by different color-nodes of the forward one, backward one and the featured one with the same sequential position of another ring. However, a critical infrastructure-path may have several lanes for traffic; hence, the double-ring network is not an ideal prototype for reliable traffic management in relatively wide critical infrastructure-paths. Nevertheless, the objective of the optimal degree being three can be set as a criterion for establishing our dual-surveillance based SCADA network prototypes.

### 2.2 Properties of GHT for Dual-Surveillance Based Networks

Any node of  $GHT(m,n,d)$  has three links; hence,  $GHT(m,n,d)$  is a 3-regular bipartite graph.  $GHT(m,n,0)$  is the honeycomb rectangular torus, or  $HReT(m,n)$  which can be fitted into a three-dimensional doughnut-like shape;  $GHT(m,n,n/2)$  can be adapted to a pipe-like shape (Figure 1). In this article,  $GHT(m,n,0)$  and  $GHT(m,n,n/2)$  are proposed for intended dual-surveillance based SCADA or GHT-SCADA networks.

In critical situations, the *1-edge hamiltonian* property can offer one edge fault-tolerance for continual operating of the GHT-SCADA network in the normal ring-structure; however, the ring-SCADA network basically needs to operate in the linear-structure if it has one broken link. It means that the GHT-SCADA network has more edges' fault-tolerance than the ring-SCADA network. Similarly, the  *$I_p$ -hamiltonian* property can offer the GHT-SCADA network to have more nodes' fault-tolerance than the ring-SCADA network can have.

However, due to the property of bipartite networks, instead of one node, two nodes of different parties are logically considered together for proving hamiltonian properties; in other words, if one node is concerned for fault-tolerance, another node of different bipartition is arbitrarily chosen for fault-tolerance concern. Moreover, both *1-edge hamiltonian* property and  *$I_p$ -hamiltonian* properties can benefit checking and maintenance in a sequential-order environment, which is important for reliable operational management in large-scale critical infrastructure-paths.

In our dual-node network application, the mechanisms are aimed to provide: (1). Better functionality just as the human beings can have better vision by two eyes instead of by one; (2). More fault-tolerance in both nodes and links than the single-node or ring network for real-time traffic management; (3). Capability of executing efficient/effective checking or maintaining for a SCADA network in a systematical sequential-order environment. These three

mechanisms are considered important for the SCADA network in disaster-sensitive or large-scale critical infrastructure-paths although other features, such as performance criteria, are also needed.

### 2.3 Graph Concepts of Applications and Proofs

Topology is the geometry of position that deals with patterns of continuity, relative positions or space properties that remain unchanged no matter how the spaces are bent, stretched, shrunk, or twisted. However, the network topology will often affect the physical shape and related costs or values [15]. The above concept is important for sketching the scope of this research. Most critical infrastructure-paths can be imagined as tubes of flowing vehicles, the typical example is a pair of parallel tubes, which can have different dimensions or maybe curved, but generally with two directions. However, a single tube still can be partitioned to accommodate two directions of vehicle flow.

Moreover, the shape of the three-dimensional configuration of  $GHT(m,n,0)$  network can be like a doughnut-shaped skeleton, and can easily be adapted for the wire connecting spaces of a pair of highway critical infrastructures (Figure 1). The  $GHT(m,n,0)$ /HReT network, which can be extended in both length and width dimensions, can well fit a path-structure of more than two lanes, and for a path-structure composed of two or more path-structures closely adjoined together in one direction.

Nevertheless, the twin-tube configuration can be adapted for single-tube roads or path-structures since each of the two-way directions of traffic can be accommodated in a virtual path-structure. Hence, the infrastructure-path configurations can be considered as the composition of the single-tube path-structures and the twin-tube path-structures.

Since operation management facilities should be arranged according to reasonable physical conditions, the longer the path of infrastructure is, the more the number of SCADA-nodes along its length is naturally increased. This number can be indexed as  $n/2$ , and  $n$  is the second coordinate of the  $GHT(m,n,0)$  / HReT network. The first coordinate,  $m$ , which is also an even integer, is the number of nodes in a cross-section of the infrastructure-path of dual-node SCADA network. The scope of the dual-node SCADA network for longer path of infrastructures can conceptually be embedded by a pair of dual-node rings gradually (Figure 1, 2).

Hence, mathematical properties of such networks can be considered from small-scale to large-scale or physically embedding with one pair of dual-node rings recursively. Once the  $1$ -edge hamiltonian, the  $1_p$ -hamiltonian and the hamiltonian laceable properties are found for small-scale HReT networks, probably through exhaustive searches, these properties are possibly be extended to large-scale HReT through the concept of embedding a pair of dual-node rings in the width dimension,  $m$ . In Figure 2, the proof of the mechanism of ring embedding is illustrated. However, the embedded place should have at least one link in the hamiltonian cycle, and irregular cases need to be considered separately [4,9,10,11].

Each embedded location of the former hamiltonian cycle can naturally get two end-points when one link of the hamiltonian cycle is broken. These two end-points can be extended to two arms which hold the embedded dual-rings. All nodes of the embedded dual-rings can be passed just once through “swing” shapes with arms formed by the former hamiltonian cycle, and then a hamiltonian cycle/path is found for the wider scaled torus. In Figure 2, the movement can be deemed as moving along an up-moving “swing” and the pedal of the swing is just below the next pair of arms or its own arms if there is only one location for embedding. However, just as the movement in the globe, the upward direction has only the index meaning, such as the  $n$  in  $GHT(m,n,0)$ .

Since the recursive embedding of rings can help prove the existence of hamiltonian properties from small  $m$  to large  $m$ , and this is related to the width of critical infrastructure-paths. The length dimension,  $n$ , is generally very large in the intended applications; however, from basic searching results,  $m$  can be 2 or 4 for basic proof considerations, and then the ring-embedding tactics can be applied for proving hamiltonian properties.

After adaptation of a dual-node ring by bi-folding (Figure 1),  $GHT(m,n,n/2)$  can be a configuration with good order as  $GHT(m,n,0)$ , and the length of the tube configuration can be indexed as  $n/2$ . Similarly, the  $m$  dimension or width dimension of  $GHT(m,n,n/2)$  can be extended by a pair of dual-node rings gradually [9,10,11]. Also, similarly, the recursive embedding of rings can help prove the existence of hamiltonian properties from small  $m$  to large  $m$ .

Considering from basic searching results for recursive proof of hamiltonian properties,  $m$  needs to be analyzed on 2, 3 or 4, and the ring-embedding tactics can be applied for them. As in [9], we can find that fixed hamiltonian patterns are achieved when  $n$  is large enough, and the result of  $GHT(m,n,n/2)$  is similar to that of  $GHT(m,n,0)$ ; however, those cases need to be viewed from 3D perspectives.

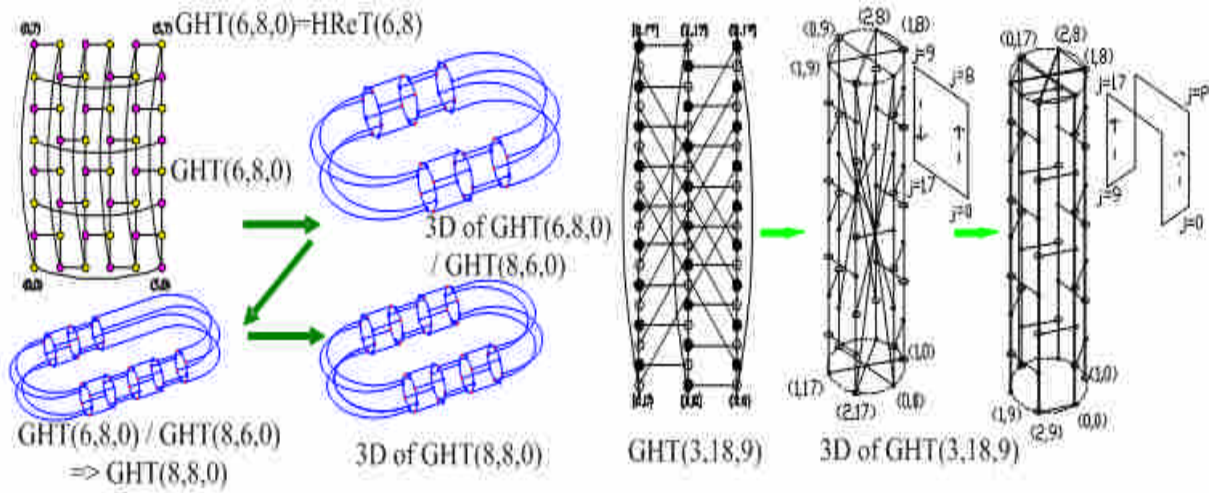


Figure 1. Three dimensional presentation of  $GHT(m,n,0)$  and  $GHT(m,n,n/2)$

2D presentation of ring embedding (only show hamiltonian cycle)  $\blacktriangledown$

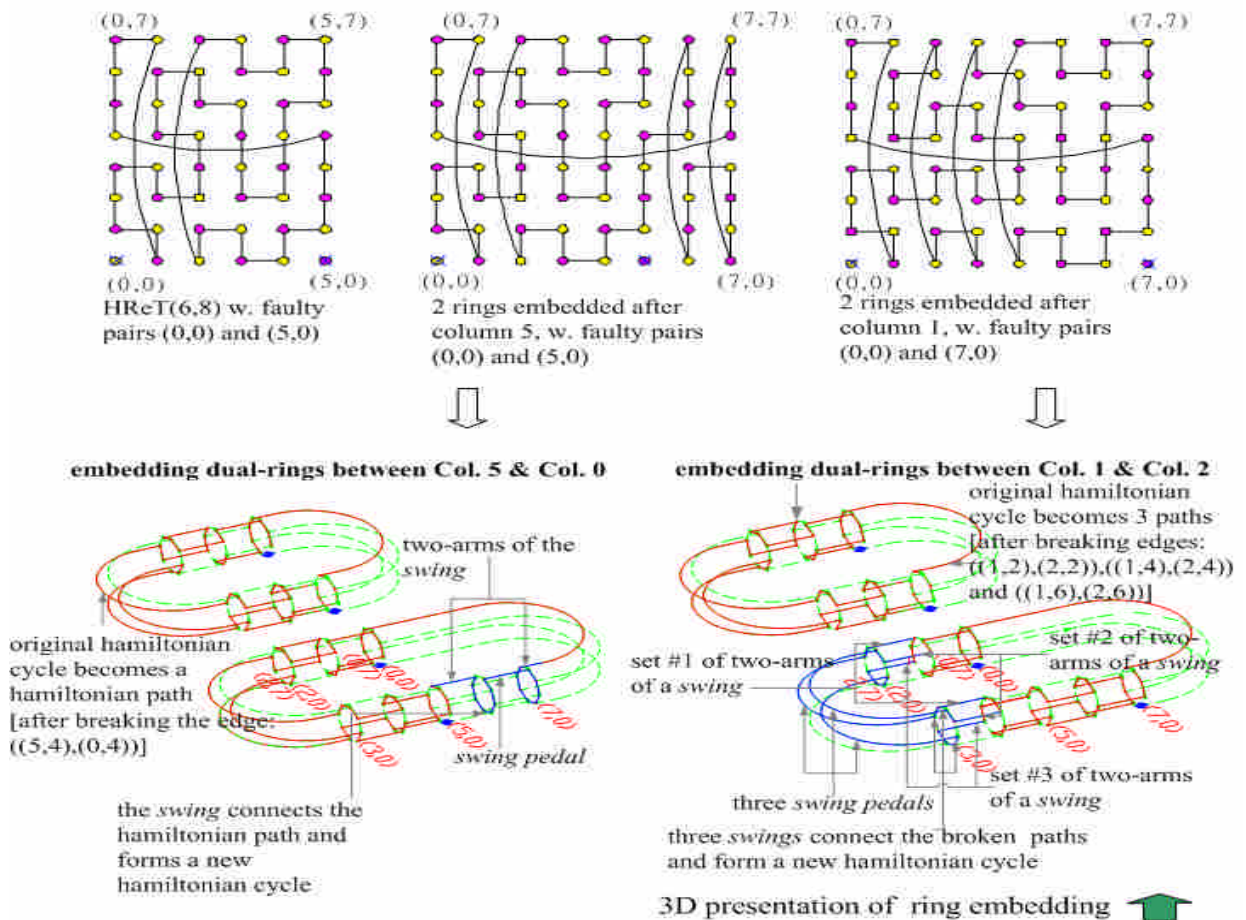


Figure 2. Ring-embedding tactics for proving  $GHT(m,n,0)$  hamiltonian from small-scale to large-scale

### 3.0 Significance

#### 3.1 Preventing Sight-Line-Obstruction by Dual Surveillance

Good security should require careful access control, waste disposal systems (probably bombs can be hidden) and sophisticated management plans [8]. However, on a busy street, the terrorist behaviors or any sabotage incidents can easily be blocked by people, vehicles or other objects. Therefore, considering the dual-surveillance system with capability of preventing sight-line-obstruction is worthwhile for strengthening security operation.

Furthermore, in proposed GHT-SCADA systems, having systematical-order mechanism as well as fault-tolerance capability can be controlled from whole area aspects and with high reliability. Nevertheless, in such a mechanism, the whole security system still can be adaptively zoned according to specific task requirements.

#### 3.2 Integrating Individual Security Networks to a Large Compound Network through Hamiltonian Laceability

GHT networks (i.e.,  $GHT(m,n,0)$  and  $(GHT(m,n,n/2), n \geq 4)$ ) can have both hamiltonian property and hamiltonian laceability. Since there is a hamiltonian path between any pair of nodes of different bipartites, two GHT networks can be easily combined to have a compound hamiltonian cycle. Therefore, if individual GHT-SCADA networks are arranged in both “W-E”-direction streets, such as: A, B, C, D, E; and “N-S”-direction streets, such as: W, X, Y, Z (Figure 3), we can establish a hamiltonian cycle to accommodate all above SCADA networks under the hamiltonian laceable mechanism, and a systematic order can be built up to benefit intra-operations in the critical area.

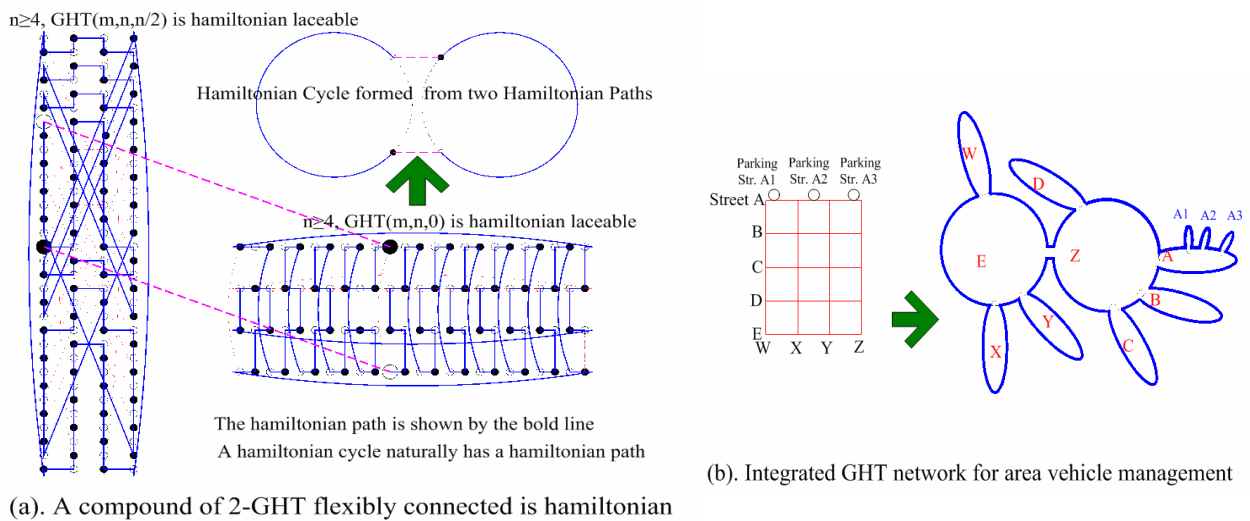


Figure 3. Integrate an area hamiltonian GHT-SCADA network with hamiltonian laceability

#### 3.3 Integrating Streets and Buildings for Vehicle Security or Parking Management

Moreover, in our proposed system, the hamiltonian laceability can also help integrate the GHT-SCADA networks designed for buildings, or more specifically, for parking structures, with the street SCADA networks as a whole system. Therefore, an integrated SCADA network for vehicle security or parking management can be established in a critical area.

Because approximately 80 percent of terrorist attacks rely on explosive devices hidden in vehicles near target buildings [8], and parking structures especially below buildings are potential terrorist targets [8], considering an integrated SCADA system for vehicle security in a critical area is essential. However, the SCADA network function is not limited to security. It is also good for the parking management or for the whole intelligent transportation systems.

## 4.0 Conclusion

After September 11 event, the risks of terrorist events or vehicle security management cannot be overlooked. Hence, a SCADA (supervisory control and data acquisition) network with distributed intelligence and a real-time fault-tolerance mechanism are worthwhile for all streets or even parking structures in critical areas. The ring network of regular degree being two is generally utilized for links' fault-tolerance as well as providing a mechanism supporting orderly inspection and maintenance, and spares may be arranged to support nodes' fault tolerance. However, spares are inefficiently used in normal conditions and may have difficulties to support real-time processing. Therefore, in this paper, bipartite GHT (generalized honeycomb tori) are prototyped as dual-node/dual-surveillance based networks, whose "degree" are optimal (three) and are suggested for the infrastructure-paths or vehicle management of the critical areas. The features of the bipartite GHT network are:  $GHT(m,n,0)/GHT(m,n,n/2)$  is 1-edge hamiltonian and hamiltonian laceable if  $n \geq 4$ ,  $GHT(m,n,0)/GHT(m,n,n/2)$  is 1p-hamiltonian if and only if either  $n \geq 6$  or  $m = 2$  and  $n \geq 4$ . The dual-surveillance GHT-SCADA network prototypes have three mechanisms: (1). Better functionality just as the human beings can have better vision by two eyes instead of by one; (2). More fault-tolerance in both nodes and links than the single-node or ring network for real-time traffic management; (3). Capability of executing efficient/effective checking or maintaining for a SCADA network in a systematical sequential-order environment. Such reliable SCADA networks not only can prevent disasters, but also can actively provide best judgment and the control of incidents, or help areas' e-development.

## 5.0 References

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