DATA TRANSMISSION NETWORK

FOR GREENHOUSE GAS EMISSION INSPECTION

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ABSTRACT:

Exhaust from construction equipment is one of the major sources of Greenhouse Gas emissions in the construction industry. And collecting, monitoring, and managing equipment emissions in a real time environment will help ensure contractor's compliance with applicable emission regulations and contractual requirements. Existing emission compliance systems, however, fail to address the complexity of construction operations. This paper presents an ad hoc network optimization model for construction equipment emission inspection. Equipment specific emission data is collected by a device attached to each vehicle and transmitted through the ad hoc network to reach the data processing server. The optimal data transmission mechanism is modeled for minimizing data loss during transmission. The paper also demonstrates the highly efficiency and accuracy of the model through a simulation of various equipment distribution patterns and a discussion of relaxed transmission capacity.

KEY WORDS:

Greenhouse Gas Emissions, Inspection, Ad hoc network, Construction Project

1 INTRODUCTION

There is general scientific consensus on global warming and that the warming is primarily due to anthropogenic activities grown since pre-industrial times (Pachauri, 2007). According to the EPA's GHG emission report (U.S. EPA, 2008), the construction sector produced 6% of total U.S. industrial GHG emissions in 2002, and has the third highest GHG emissions among the industrial sectors. The major source of the construction sector is fossil fuel combustion (76%), which is the use of fossil fuels, such as gasoline, diesel, or coal, to produce heat or run equipment.

In order to control the GHG emission of the whole construction project lifecycle, especially the construction stage, US EPA has put forward many related programs or regulations, such as Diesel Emissions Reduction Program (U.S. EPA, 2005), Idling Reduction Program (U.S. EPA, 2010), and Clean Fuel Program (U.S. EPA, 2000). Project owners usually incentivize their contract bidders by producing green contracts

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involving the emission control technology or strategy packages as required or optional provisions.

However, it is practically difficult to generate a measurable and enforceable operation pattern for green construction equipments. It is even harder to control in a project level that contractors are complied with regulations or provisions in the contract. Therefore, a real-time construction project monitoring system for GHG emission is increasingly important to:

1) Help to collect information about the GHG emission during the whole lifecycle of the project so as to correctly estimate the total actual impact to the field environment.
2) Help to provide baseline data for the construction process so as to establish a standard for green contract performance evaluation.
3) Monitor contractor’s construction equipment behavior so as to ensure that the process is complied with provisions in the green contract.
4) Timely provide contractors with reminders or warnings once abnormal information is detected by the inspection system.

In this paper, we consider a general construction project where different fleet equipments are operating within the construction field. Each piece of equipment has a device installed so as to collect and transfer the emission data to the central processing server. An ad hoc wireless sensor network is designed for better collecting information. An algorithm of data transmission protocol between devices is established for minimizing data loss during transmission. A simulation of various equipment distribution patterns is then conducted to demonstrate the efficiency and accuracy of the model. Different influence factors are discussed in the end for the model limitation and future improvement.

2 DESIGN OF THE INSPECTION NETWORK

In order to establish a real-time network, we will need to design a data transmission scheme with devices installed in construction equipments. Different from static systems, construction equipments are usually moving within a limited field range, which makes it hard and infeasible to resort to wired connections between devices. Therefore, we come to an idea of wireless sensor network to realize the data transmission mechanism.

A wireless sensor network could be either centralized or decentralized (Toh, 2002). In a centralized network each sensor communicates with base stations and the base stations are responsible for connecting and routing. In a decentralized network like an ad hoc network there is no pivot above the sensors. Instead, each sensor is responsible for routing and data transmission with other sensors.

Such ad hoc networking is more suitable for a construction project context. In a construction site, we expect a good portion of equipments (cars, tractors, bulldozers etc) are moving in a wide range of field area, sometimes randomly. It might be hard to design a base station layout when too many base stations raise cost substantially and too few base stations reduce coverage. With ad hoc networking, we don’t need to worry about base station installation, and we could take advantage of free public spectrum to further reduce cost.

We try to take advantage of ad hoc networking to realize real time greenhouse gas monitoring. To set up, we need one device for each piece of equipment in use, and a data server to receive data from the device with all post data analysis functionality. Each device consists of a sensor module, a receiving module, a transmitting module, a controlling module, a positioning module (Mohapatra & Krishnamurthy, 2004). The functionalities of all the modules are:

1) Sensor module: collect greenhouse gas emission data. Sensor module will generate monitoring data in a certain speed and output to transmitting module. Non-dispersive Infrared (NDIR) sensors are most often used for measuring the concentration of CO_2 (Lang, Wiemhöfer, & Göpel, 1996) through testing the wavelength characteristic of infrared.

2) Receiving module: receive data within a certain range from other devices in a certain speed. In an ad hoc network, each device should be able to receive data from other devices if they cannot reach the data server or it is better through this device for less transmission loss.

3) Transmitting module: send data within a certain range out to other devices or data server in a certain speed. Since we want a real time ad hoc network, the transmitting speed should be large enough to consume the data generated by the sensor module and accommodate other far-end devices at the mean time.

4) Controlling module: in charge of routing control. The controlling module maintains a distribution picture of all available devices with in its range. It reads the information from the positioning module to get the distance between every device to itself. From all the information the controlling module should design a transmission strategy in order to transmit all local data out. The algorithm designed in this paper is focusing on this module.

5) Positioning module: provide absolute position of the device. We need to get the position of the device to generate the distribution picture for the controlling module. Commonly, positioning system like GPS will work (Xu, 2007).

With all these modules each device could send and receive data from the devices/server within its transmission range. If a device is out of the range of the server, it has to find a multi-hop route to the server via several devices and transmit data to them to finally reach the server.

3 INSPECTION NETWORK TRANSMISSION MECHANISM

3.1 Assumptions

In order to design a feasible and reasonable wireless ad hoc sensor network, several assumptions need to be made for the system. Notations are shown in table 1.

1) There are N pieces of equipment (with N devices) and a data server in the network. Data server could only receive data from equipments, while equipments could both send and receive data from their peers.

2) To send data across distance d, there is a data loss proportional to d. The data loss is regarded as the transmission cost in our model.

3) Each device will generate emission data in a constant speed (g).

4) Each device has a transmission capacity limit (tc); total flow sending out from the device cannot exceed the limit.

5) Each device and the data server have a transmission range. They could only transmit data to other devices within the range.
6) Equipments are moving in the construction field. It is highly possible that at a certain time point a device is within the range of the other and later it is not.
7) All devices are synchronized at any time. They all keep the same picture and information at a certain time about how all the devices are distributed.

Table 1 Table of Notation for the Transmission Model

n	Number of equipment
X_{ij}	Transmission flow from node *i* to node *j*
X_{ik}	Transmission flow from node *i* to server or dummy node
C_{ij}	Unit data loss of transmission flow from node *i* to node *j*
C_{ik}	Unit data loss of transmission flow from node *i* to server or dummy node
g	Data flow generated by each device
tc	Total transmission capacity for each device

3.2 Transmission Model

Based on the assumptions made for the transmission mechanism, we could formulate the problem as:

$$min\left(\sum_{i=1}^{n}\sum_{j=1}^{n} C_{ij}\cdot X_{ij} + \sum_{i=1}^{n}\sum_{k=server}^{dummy} C_{ik}\cdot X_{ik}\right) \quad \text{Eqn 1}$$

$$subject\ to$$

$$for\ i = 1\ to\ n,\ \sum_{j=1}^{n} X_{ij} + \sum_{k=server}^{dummy} X_{ik} = g + \sum_{j=1}^{n} X_{ji} \quad \text{Eqn 2}$$

$$for\ i = 1\ to\ n,\ \sum_{j=1}^{n} X_{ij} + X_{i,server} \leq tc \quad \text{Eqn 3}$$

$$X_{ij} \geq 0, X_{ik} \geq 0$$

First of all, it is necessary to introduce the dummy node in the model for some potential imbalanced node. If a device cannot find a way to transmit data out to other devices, it could always go to the dummy node. The total flow going into the dummy node represents the total data loss of the system. Of course, dummy node does not send out any data.

With this being said, we have two types of data transmission cost. The first one is caused by distance, and it is proportional to the distance. The second one is the total amount of data lost, which is the total flow sending to the dummy node. Therefore the objective function Eqn 1 is to minimize the total cost of the system.

Eqn 2 is the flow balance constraint. For each node, the flow sending out to other nodes (including the server and the dummy) should be balanced with the data it generates and the flow it receives from other nodes.

Eqn 3 is the transmission capacity constraint. For each node, the total flow it sends out should be under a certain transmission capacity limit *tc*.

4 NUMERICAL ANALYSIS

In order to examine the effectiveness and efficiency of the model, a simulation process is conducted with different time point. The simulation is to depict a general construction site with normal equipment activities, while typical locations of the equipment are designed representing some normal or extreme cases for the network transmission.

4.1 Basic Parameters

We consider a construction field with dimension of 3 miles by 2 miles. There are altogether 6 equipments moving in the field, represented by node 1 to 6. The data server and the dummy node are two additional nodes.

The data server, as well as all devices have a transmission range L=1 mile. The sensor module on each device is generating information in the flow of g=2 units/s. Each device is transmitting data out to other devices, including the server, within a flow capacity limitation of tc = 5 units/s.

4.2 Absolute Positions

Since the equipments are moving within the construction field, the absolute position of each device is changing with time. Therefore, we need to design a series of position scale (x,y) for each device. We consider the following four special cases, and other general conditions could be regarded as combinations of these cases.

1) All equipment are in the range of the server
2) Only one equipment is out of the range of the server
3) Only two equipment is in the range of the server
4) One equipment is in the very end of the field and no other equipment is in the range of it

Since the server is not moving, and generally is set in certain condition by the side of the construction field, we set the static server position as (*0*,*3*). Hence the position scales of the 6 equipments could be given as:

Table 2 Four Cases of Locations for Six Construction Equipment

	Case 1		Case 2		Case 3		Case 4	
Node	**x**	**y**	**x**	**y**	**x**	**y**	**x**	**y**
1	2.2	0.1	2.6	0.5	2.6	0.8	2.2	0.4
2	2.3	0.6	2.1	0.2	1.8	0.9	2.6	0.9
3	2.5	0.8	2.9	0.9	2.2	0.5	1.8	1.4
4	2.8	0.9	2.3	0.7	1.4	1.4	1.4	0.5
5	2.9	0.4	2.8	0.2	1	0.5	1	1.1
6	2.5	0.3	2	1.2	0.6	1.2	0.2	1.8

4.3 Cost Coefficients

Then we need the cost coefficients among each pair of the nodes to calculate the data loss. As discussed in the model, if a certain node is in the transmission range of another node, the cost of the flow is proportional to the distance d between them, and we simply set the multiplier as 1. If a device is out of the range of another device, the cost equals to a very large number, and we set it as M_1=1000. Since the flow is not allowed to send to the node itself, we set the cost of Xii, cii=1000. Meanwhile, since the flow sent to the dummy node represents the information that is lost, we need to allocate a fairly large cost to those flows but smaller than the out-of-range cost. We set it as M_2=500. Therefore, the cost coefficients could be written as:

$$c_{ij} = \begin{cases} d_{ij}, & if\ d_{ij} \le 1,\ \ i = 1,..,6,\ \ j = 0,..,6, i \ne j \\ 1000, & if\ d_{ij} > 1,\ \ i = 1,..,6,\ \ j = 0,..,6 \\ 1000, & if\ i = j \\ 500, & j = dummy \end{cases} \qquad \text{Eqn 4}$$

5 DISCUSSION OF SIMULATION RESULTS

5.1 General Cases

Given the parameters, the transmission pattern could be solved through the model:

Table 3 Simulation Result

	X_{21}	X_{31}	X_{41}	X_{51}	X_{61}	X_{32}	X_{42}	X_{52}	X_{62}	X_{43}	X_{53}	X_{63}	X_{54}	X_{64}	X_{65}
Case 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Case 2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Case 3	2	0	0	0	0	-3	2	1	0	0	0	0	0	0	0
Case 4	0	0	3	0	0	3	0	0	0	0	1	0	1	0	0
	$X_{1,s}$	$X_{2,s}$	$X_{3,s}$	$X_{4,s}$	$X_{5,s}$	$X_{6,s}$	$X_{1,d}$	$X_{2,d}$	$X_{3,d}$	$X_{4,d}$	$X_{5,d}$	$X_{6,d}$			
Case 1	2	2	2	2	2	2	0	0	0	0	0	0			
Case 2	4	2	2	2	2	2	0	0	0	0	0	0			
Case 3	4	0	5	0	0	0	0	0	0	0	1	2			
Case 4	0	5	5	0	0	0	0	0	0	0	0	2			

Case one: all devices are located within the range of the data server (Figure 1). In this case, since the cost coefficients are equal to the distance between device and data server, each device will transmit its own data (2 units) to data server. There is no data flow among devices and dummy node.

Case two: device #6 is located outside of the range of the data server (Figure 2). Since device #6 cannot transmit data to data server directly, it has to transmit its data to device #1 and then device #1 sends all incoming data (4 units) to the data server. All other devices are transmitting data directly to data server.

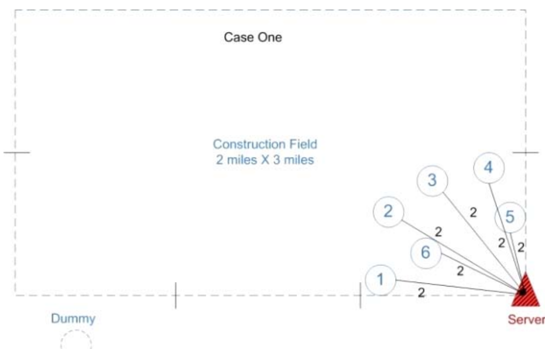

Figure 1 Case One

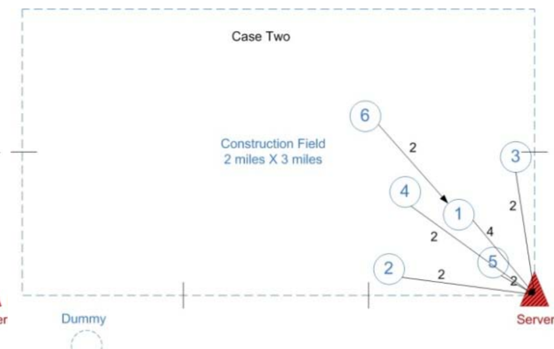

Figure 2 Case Two

Case three: only devices #1 and #3 are located within the range of the data server (Figure 3). Device #2 is the bottleneck here since devices #4, #5, #6 have to pass through it to reach the data server. However with the capacity limitation, device #2 is not able to transmit all the data, hence there is data loss of 3 units (data sent to dummy). Device #2 distributes the data it receives to device #1 and #3 respectively.

Case four: device #6 is located without the range of any other devices (Figure 4). In this case, device #6 simply has no other choice but lose all its data. Device #1 and

Device #2 has used up all their transmission capacities, 5 units.

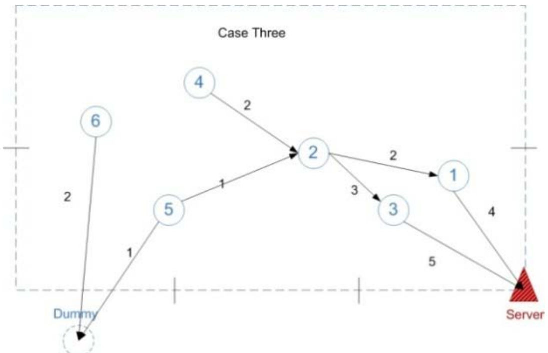

Figure 3 Case Three

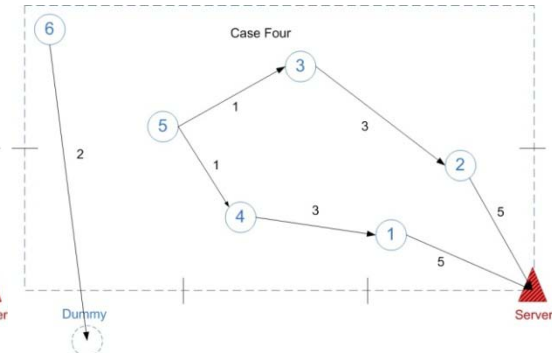

Figure 4 Case Four

5.2 Improved Cases with Relaxed Capacity Limit

There are a number of factors which could affect the final transmission pattern, e.g. cost coefficients, device distribution (distance matrix), ratio of data generation speed and transmission capacity etc. In this section we'd like to fix the other parameters and discuss how increasing transmission capacity could improve the system. We take case three and four as examples. Relaxing the capacity limit from 5 to 8 units/s, the new transmission patterns are solved in Table 4.

Table 4 Simulation Result for Relaxed Capacity

	X_{21}	X_{31}	X_{41}	X_{51}	X_{61}	X_{32}	X_{42}	X_{52}	X_{62}	X_{43}	X_{53}	X_{63}	X_{54}	X_{64}	X_{65}
Case 3	2	0	0	0	0	-6	4	2	0	0	0	0	0	2	0
Case 4	0	0	4	0	0	2	0	0	0	0	0	0	2	0	0
	$X_{1,s}$	$X_{2,s}$	$X_{3,s}$	$X_{4,s}$	$X_{5,s}$	$X_{6,s}$	$X_{1,d}$	$X_{2,d}$	$X_{3,d}$	$X_{4,d}$	$X_{5,d}$	$X_{6,d}$			
Case 3	4	0	8	0	0	0	0	0	0	0	0	0			
Case 4	6	4	0	0	0	0	0	0	0	0	0	2			

For case three, now with sufficient capacity, device #4, #5 and #6 are able to transmit all their data to device #2, which re-distribute the flow to device #1 and #3 (Figure 5). The data loss of the system is reduced.

Similarly, for case four, with the relaxation of capacity limit, the system takes more advantage of the low-cost path (device #5 send data through 5–4–1–Server instead of 5–3–2–Server) (Figure 6). However, increasing capacity could not improve device #6 whose data are still lost due to out of range.

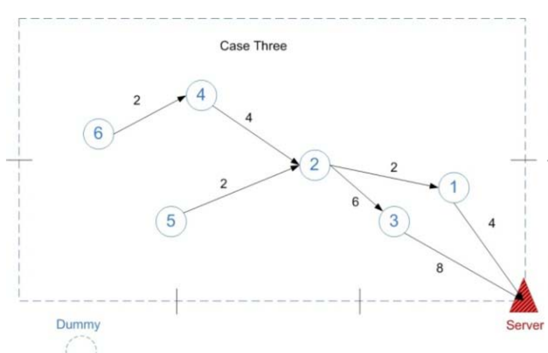

Figure 5 Case Three with Relaxed Capacity

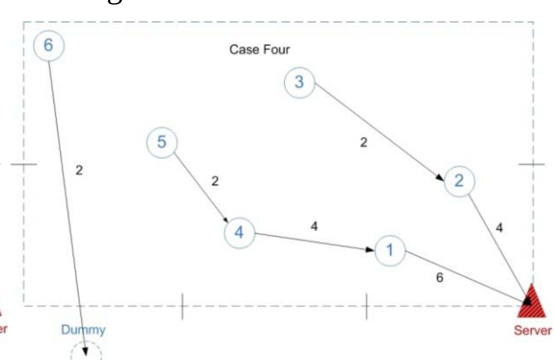

Figure 6 Case Four with Relaxed Capacity

6 CONCLUSIONS AND FUTURE WORK

In this paper, we consider a real-time ad hoc wireless network for construction project GHG emission inspection. The network transmission model is established. Through solving cases with different equipment distribution, and transmission capacity, we could draw the following conclusions:

1) The programming model works perfectly for depicting the data transmission network, and the results are in accordance with our expectations.

2) Four cases of equipment distribution positions are discussed. The data transmission pattern is depending on cost coefficients, device distribution (distance matrix) and ratio of data generation speed and transmission capacity etc.

3) Relaxing capacity limitation could reduce data loss in the transmission. However, it could not improve the "out of range" situation.

With basic research results from this paper, we would like to continue our work through the following aspects in the future:

- For this project we only discussed simple cost coefficients which are proportional to distance. In a more realistic model we should use different coefficients e.g. exponential to distance.
- We could consider a storage module which would help to address the "out of range" issue and further improve the network transmission performance.
- We would like to cover more pieces of equipment to better simulate a practical construction field. With more equipment in the network, the transmission pattern will change a lot, and the analysis of improvement factors will be more complicated.
- All the analysis is based on fixed time. A real time animation will be more interesting and make the model easier to understand.
- To really examine the model, it will be helpful to do some real experiments. We could also conduct some post data analysis like operation pattern recognition.

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