

Droplet Routing in DMFB based on Minimum Weight Number of Alternate Paths

Pabitra Roy, Subrata Das

Abstract- Microfluidic biochips rely on the principle of electrowetting on dielectric. Discrete droplets of nanoliter volumes can be manipulated in a digital manner on a two dimensional electrode array. Due to recent advances on microfluidic technology digital microfluidic biochips has gained much attention. One of the major problems on digital microfluidic biochips are droplets routing problem. In this paper we proposed a droplet routing method based on minimum weight number of alternate paths. We first calculate number of paths for each net based on minimum weight. Here each droplet has a single source and single target location. The main objective in routing is to find droplet routes with minimum length where route length is measured by the number of cells in the path from source to target location. The algorithm is implemented by using C++ and the results obtained are quite encouraging.

Keywords- Digital microfluidic biochip, droplet routing, electrowetting, Lee algorithm.

1 INTRODUCTION

Microfluidic biochips offers a promising platform for DNA analysis, automated drug discovery [5], real time biomolecular recognition, developing clinical and diagnostic application, such as health care of infants and point of care diagnostics of disease. This breadth of applicability implies that microfluidic biochips are increasingly used in laboratory procedures in molecular biology [2]. The technology lab on a chip (LoC), offers promising technology to a conventional biochemical laboratory

To reduce geometrical dimension, required reagent volumes, saving material cost, microfluidic based systems provide results of enhanced precision compared to the conventional biochemical analyzers [7]. Droplet based biochips are referred to as digital biochips; deal with discrete droplets on a two dimensional electrodes assay.

In integrated circuits (ICs), routing complexity increases with an increase in the complexity and the number of bioassay operations that are mapped to a digital microfluidic platform.

Synthesis procedure of DMFB (digital microfluidic biochip) includes optimization cost functions with the optimized utilization of resources viz. Electrode timing constraint etc [1]. In this paper we proposed an approach to route multiple droplets with the use of minimum number of electrodes form source to target locations and reduce total routing time. Our method consists of two phases. In phase_I we first calculate number of possible paths for each droplet having minimum weights. The weight is calculated by wave propagation (Lee Algorithm). In phase_II we arrange the droplets in ascending order of their number of paths. Net ordering greatly affects the routing solution. After that for all droplets we have computed compatible path sets, in which all paths satisfy fluidic constraints. Rest of the paper is organized as follows, section 2 discusses some recent literature review, section 3 discusses the formulation of problem and few definitions required for subsequent discussions. Section 4 proposes the algorithm for droplet routing and explanation of the algorithm. Section 5 discusses the experimental results. Finally the paper is ended with conclusion and future work.

2 LITERATURE REVIEW

During the last decade, microfluidic biochips have become actively researched area [7]. Several optimization techniques for droplet routing have been proposed. In [6] a high performance

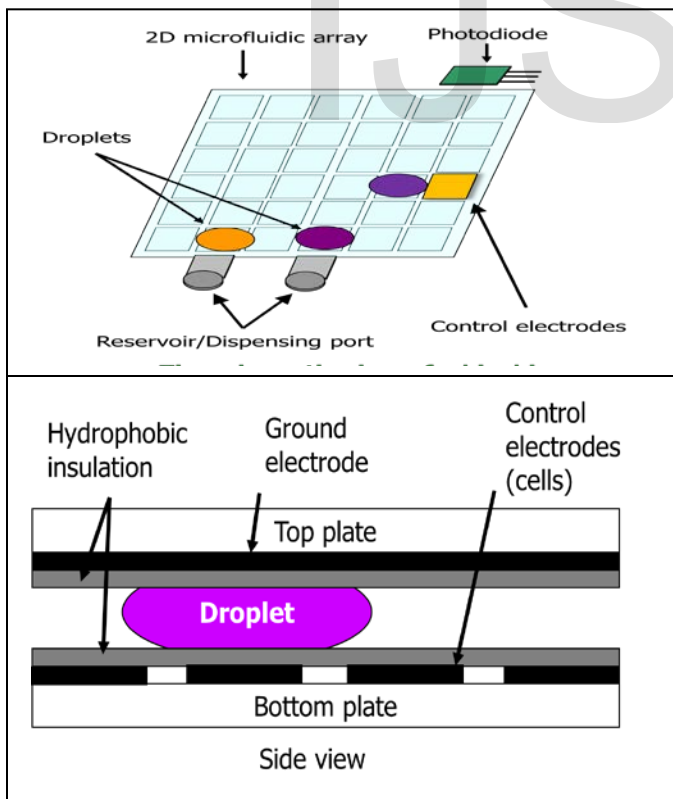


Fig. 1. Schematic diagram of Digital Microfluidic Biochip

droplet routing algorithm for digital microfluidic biochips has been proposed. In this paper Routing -Bypassibility, Routing-Concession, and Routing-Compaction have been discussed. In [1] they proposed an algorithm using Grid Graph model with the idea of CSMA/CD. They also discussed about deadlock by the mechanism Stalling and Detour. In [7] System level modelling and simulation of the cell culture microfluidic biochip procell has been discussed. In [5] a high level synthesis of digital microfluidic biochips has been proposed. Integrated droplet routing in the synthesis of microfluidic biochips has been discussed in [8]. They have presented a droplet routing aware automated synthesis tool for microfluidic biochips. In [3] a systematic routing method has been presented. Here two stage routing method has been proposed and the method is independent of routing order of nets. Here droplet routing problem is decomposed into series of sub-problem, and then M-shortest route for each net is carried out, finally selected best set of routes. In [2] a progressive ILP based routing algorithm for cross referencing biochips has been discussed. They have presented the basic ILP formulation to minimize the droplet transportation time and ILP routing scheme to iteratively determine the minimum cost positions of the droplets at each time. Experimental results also showed the effectiveness and efficiency of the algorithm.

3 PROBLEM FORMULATIONS

Droplet routing in DMFB tries to use minimum number of electrodes used to route all droplets from source to target locations, also to optimize droplet routing time. These in turn reduce routing area, throughput. Since all droplets are moving concurrent fashion, there can be unwanted mixing between droplets, while moving the droplets. Let two independent droplets at time t denoted by $d_i(x_i^t, y_i^t)$ and $d_j(x_j^t, y_j^t)$. To prevent unwanted mixing of droplets while they are moving they must satisfy the fluidic constraint for any time t during routing.

R1: Static Constraints: $|x_i^t - x_j^t| > 1$ or $|y_i^t - y_j^t| > 1$

R2: Dynamic constraints: $|x_i^{t+1} - x_j^t| > 1$ or $|y_i^{t+1} - y_j^t| > 1$

or $|x_i^t - x_j^{t+1}| > 1$ or $|y_i^t - y_j^{t+1}| > 1$

The main objective is to route all the droplets with minimize use of electrodes and routing time.

Compatible paths: Two paths are said to be compatible if they satisfy fluidic constraint (R1, R2).

Compatible path set: If all paths in a set are compatible with each other, then the set is said to be compatible path set.

3.1 DROPLET ROUTING PROBLEM

Droplet routing problem can be defined as follows. Given an array of electrodes ($n \times n$), number of droplets with source and targets coordinates of the waste cells. Route all the droplets from

source to target having shortest possible paths while considering the fluidic constraints. A successful completion of routing for all droplets from source to target locations gives minimum usage of electrodes and completion time.

4 PROPOSED METHOD

We proposed an algorithm for two_pin net droplet routing. A net is called two_pin net if it has a single source and a single target location. The algorithm attempts to find the shortest routes for each net. The objective function for the set of routes is obtained by calculating the number of cells used in routing. Droplets can move only horizontally or vertically. As the droplets are moving in parallel so they must satisfy the fluidic constraints. In phase_I we find the minimum weight for each source target location by wave propagation (Lee algorithm). Then we compute number of paths having minimum weight for each source by the algorithm_1. Lee's Algorithm guaranteed shortest path. In phase_II we use algorithm_2 for two_pin net droplet routing.

Parameter definition:

height: row difference between source and target coordinate +1.
width: column difference between source and target coordinate +1.

Path[i][j]: two dimensional array.

total_no_of_paths: total number of unique paths available to reach source to target location.

$d_i(m)$: denotes the m alternate paths of droplet d_i .

p_m, t : denotes the t^{th} path of m^{th} droplet.

Algorithm_1:

Input: source coordinate and target coordinate of each droplet.

Output: Total number of paths having minimum weight.

Step1: Find minimum weight for each source target pair to reach target location by wave propagation (Lee Algorithm).

Step2: Compute total number of paths having minimum weight by the following.

Step2.1: for $i=0$ to width-1
for $j=0$ to height-1
Paths[i][j]=1

Step2.2: for $i=1$ to width-1
for $j=1$ to height-1
paths[i][j] = paths[i-1][j] + paths[i][j-1]

Step 3: total_no_of_paths=paths [width-1][height-1]

Algorithm_2:

Input: Array of electrodes ($n \times n$); Number of droplets with source and target coordinates (m); Coordinate of waste cells.

Output: Route all the droplets from source to target having shortest possible paths.

Step1: For each droplet calculate number of possible paths from source to target coordinate having minimum weight [using Algorithm_1].

Step2: Sort the droplets according to ascending order of their number of paths. Let the order be $\{d1, d2, \dots, dm\}$.

Step3: For each droplet find all alternate paths having minimum weight. Reject those paths containing coordinates of waste cells. Let the alternate paths for each droplets are $d1(m), d2(n), d3(p), \dots, dm(t)$. Where $d1(m)$ denotes m alternate paths of droplet $d1$ and so on. Take a path $p1, i (1 \leq i \leq m)$ of $d1$. Choose a path from $d2$ in such a way that it is compatible with $p1, i$. Let $p2, j (1 \leq j \leq n)$ is compatible with $p1, i$. Then make $p1, i \cup p2, j$.

Step4: Take a path $p3, k (1 \leq k \leq p)$ of $d3$ which is compatible with $\{p1, i \cup p2, j\}$. Make $\{p1, i \cup p2, j \cup p3, k\}$ in which all paths are compatible with each other. In this way compute a compatible path set for all droplets. In compatible path set all paths are compatible with each other. Hence the compatible path set $\{p1, i \cup p2, j \cup p3, k \cup \dots \cup pm, t\}$.

4.1 Explanation of Algorithm_1:



Fig. 2. Step 1.

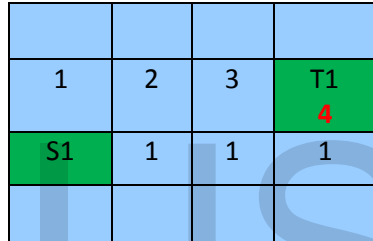


Fig. 3. Step 2 & 3.

Let S1 is the source and T1 is the target of some droplet. The minimum weight to reach target location is 4.

Number of unique paths to reach T1 having minimum weight is 4.

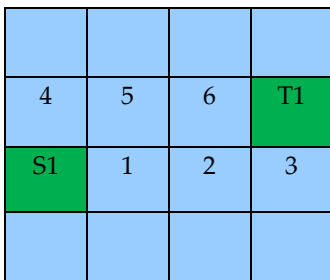


Fig.4. Four unique paths.

Four unique paths having minimum weight 4 are-

- P11: s1 -> 1-> 2-> 3-> T1
 - P12: s1 -> 1-> 5-> 6-> T1
 - P13: s1 -> 1-> 2-> 6-> T1
 - P14: s1 -> 4-> 5-> 6-> T1
- Pij: i: source
j: path number

4.2 Explanation of Algorithm_2 with an Example:

In step1 we first calculate number of possible paths for each droplet having minimum weight. Let $d = \{d1, d2, d3\}$ be the three droplets with source_target pair (Si, Ti) , $[i=1 \text{ to } 3]$. Let 6x6 array of electrodes with their source_target coordinates are given in fig. 5. Number of paths having minimum weights is shown in table 1.

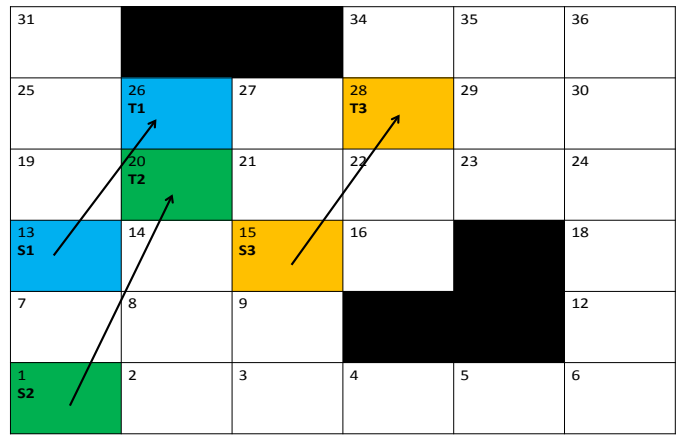


Fig. 5. Array of electrodes with source_target pair.

TABLE 1
Number of paths having minimum weight

Source_Target Pair	Minimum Weight	Number of paths having minimum weight
S1,T1= d1	3	3
S2,T2= d2	4	4
S3,T3= d3	3	3

In step2 we sort the droplets in ascending order based on number of alternate paths having minimum weight for moving. $d1 \rightarrow d3 \rightarrow d2$

In step3 we find all alternate paths for each droplet with minimum weight in table 2.

TABLE 2
All alternate paths having minimum weight

Droplets(d _i)	Source_Target Pair	Paths P _{ij} to reach S _i to T _i
d1	S1,T1	P11: S1 → 14 → 20 → T1 P12: S1 → 19 → 25 → T1 P13: S1 → 19 → 20 → T1
d3	S2,T2	P31: S3 → 16 → 22 → T3 P32: S3 → 21 → 27 → T3 P33: S3 → 21 → 22 → T3
d2	S3,T3	P21: S2 → 7 → 8 → 14 → T2 P22: S2 → 7 → 13 → 19 → T2 P23: S2 → 7 → 13 → 14 → T2 P24: S2 → 2 → 8 → 14 → T2

Droplets at different time instances in different cells are shown in table 3.

TABLE 3
 Droplets in different cells at time instance.

Time	t	t+1	t+2	t+3	t+4
Droplet					
d1,P12	S1	19	25	T1	
d3,P31	S3	16	22	T3	
d2,P24	S2	2	8	14	T2

Compatible path set $P = \{P12, P31, P24\}$. Hence the routing solution required four clock cycles to route all the three droplets to their target location. The routing solution is given in fig. 6.

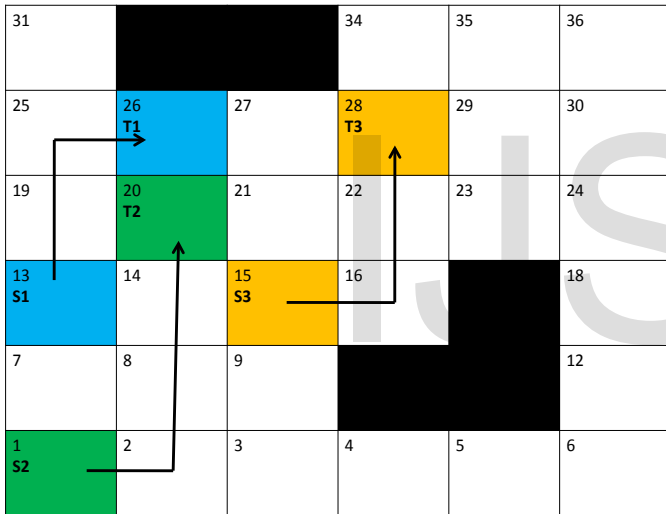


Fig. 6. Routing solution of droplets of fig. 5.

5 EXPERIMENTAL RESULTS

Table 4 shows the results obtained by running our algorithm. The experimental results are based on random test instances. The machine configuration is core i3 processor, 2.20GHz, 2GB RAM. The solution obtained gives shortest path routing solution. The numbers of unit cells are used in routing is also optimal. As Lee’s algorithm guarantees the shortest routing path so the solution obtained in our algorithm is also shortest path routing since we have considered only those alternate paths having minimum weight. Random test instances are also given in the appendix.

TABLE 4

Experimental Results on Random test instances

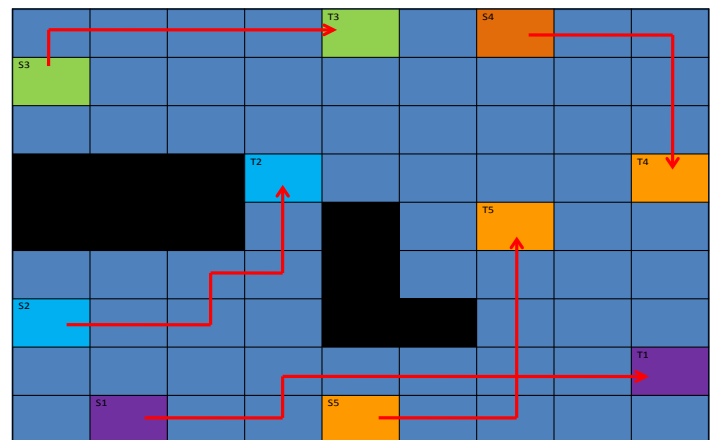
Random test instances	# of grid	# of nets	Blockage area %	Unit cell used	Move ment time	CPU time (secs)
Test1	8x8	4	0.14	29	10	0.564
Test2	9x9	5	0.12	34	9	0.321
Test3	13x13	6	20.0	55	15	0.890
Test4	14x14	10	3.34	70	12	0.612
Test5	17x17	10	10.5	79	13	0.812
Test6	17x16	10	16.50	85	18	0.672

CONCLUSION

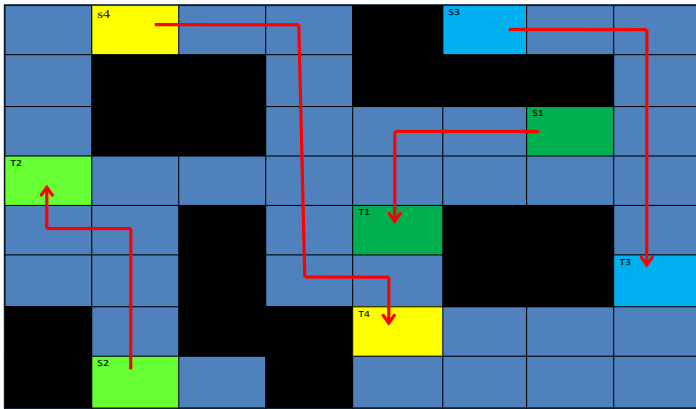
Designing a high performance routing algorithm is a goal in today’s DMFB design. We present an algorithm which gives shortest routing path solution which in turn optimizes unit cell usages also reduce total routing time. We first formulated the routing problem, where the total number of cells used for routing serves as main objective criteria. One of possible future work is to modify our algorithm for three pin nets and reduce CPU execution time.

APPENDIX

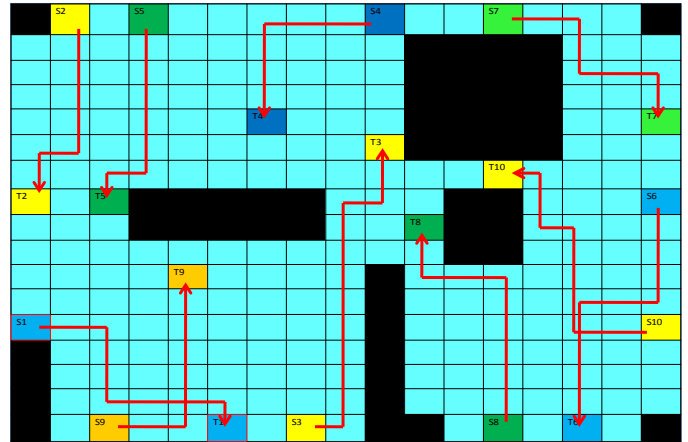
Test1:



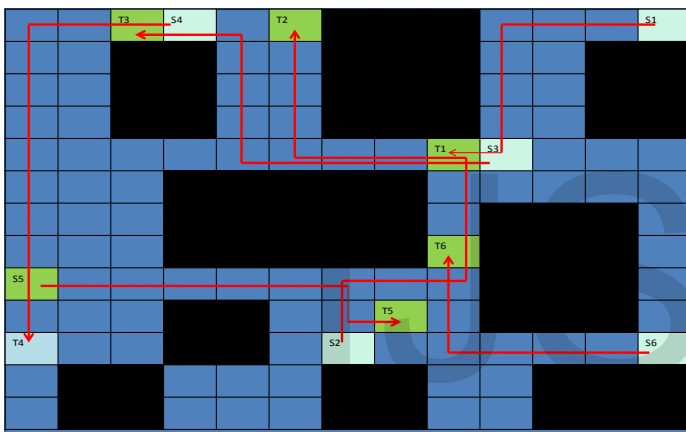
Test2:



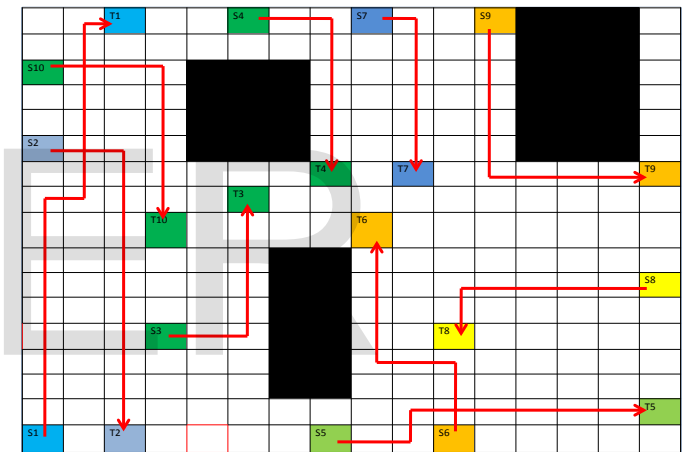
Test5:



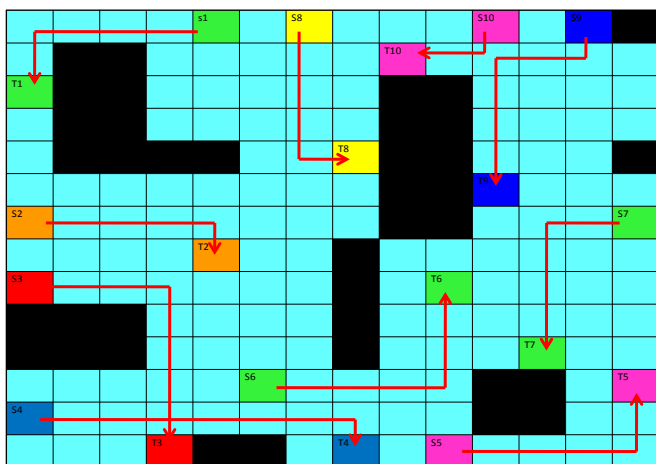
Test3:



Test6:



Test4:



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