Clustering Multi-Path Components in radio channel

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Preliminaries

- What is Multi-path Components (MPCs)?
- Why to cluster them?
- How to Cluster them?

My work

- Modified Fuzzy C-means algorithm (MFCM)
- A new clustering Framework based on MFCM
- Fusion Modified FCM (FMCM)
- A new clustering Framework based on FMCM

What is Multi-path Components (MPCs)?

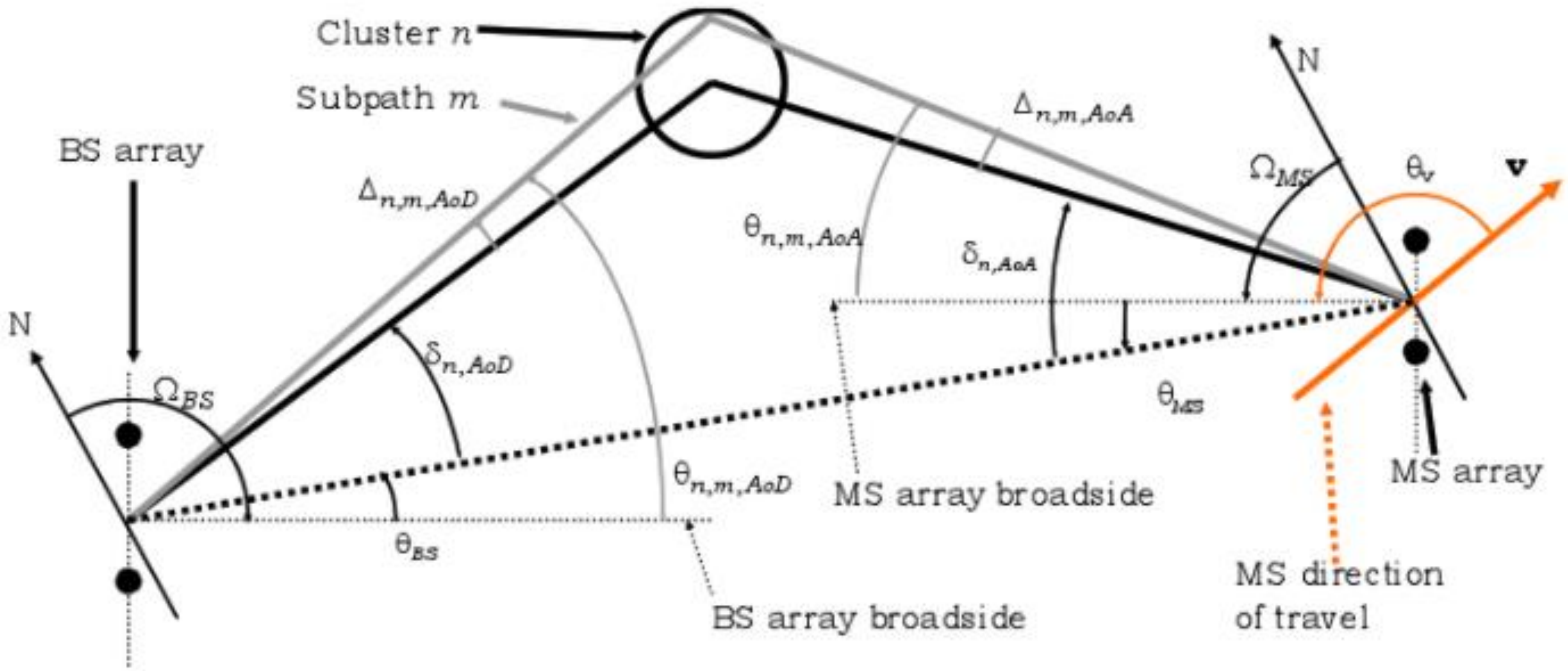


Figure 5.2: BS and MS angle parameters

3GPP Spatial Channel Model

Why to cluster them?

Delay, Power,
Angle of Departure (AOD),
Angle of Arrival (AoA)

An essential step in establishing the model

Extracting Channel Parameters from measurement data → Clustering → Establishing the model

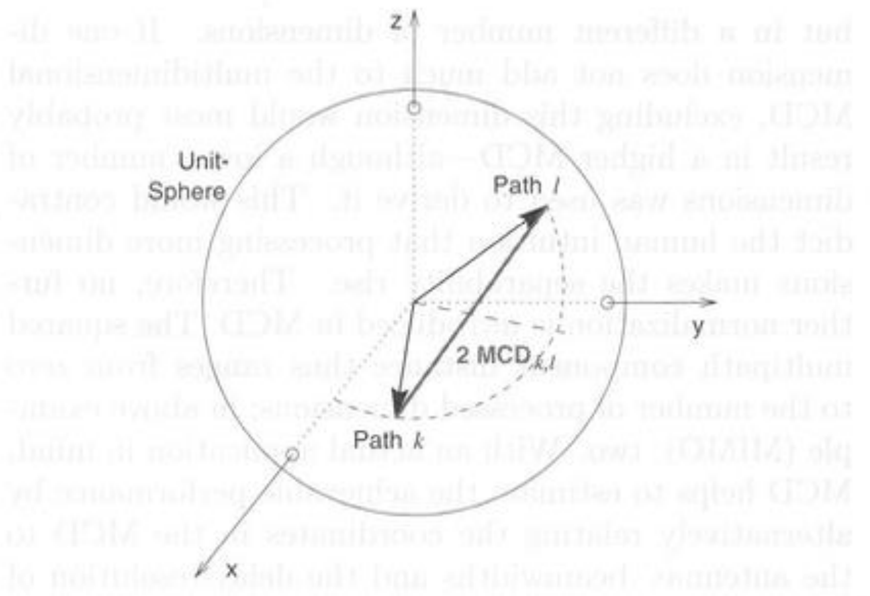
e.g. Double directional channel model

$$h(t,\tau,\Omega_T,\Omega_R)=\sum_{m=1}^{M}\{\sum_{n=1}^{N_m}P_{n,m}e^{j\Phi_{m,n}}\delta(\tau-\tau_m-\tau_{m,n})\times\delta(\Omega_T-\Omega_{T,m}-\Omega_{T,m,n})\times\delta(\Omega_R-\Omega_{R,m}-\Omega_{R,m,n})\} \quad (1)$$

How to Cluster them?

Clustering algorithms like Kmeans, Fuzzy C-means

Distance metric (similarity between MPCs) : Multipath components Distance



$$MCD_{ij} = \sqrt{\left\|MCD_{AoA,ij}\right\|^2 + \left\|MCD_{AoD,ij}\right\|^2 + MCD_{\tau,ij}^2} \quad (8)$$

$$MCD_{\tau,ij} = \frac{\tau_{std}}{\Delta\tau_{max}^2} \cdot \left|\tau_i - \tau_j\right| \quad (9)$$

$$MCD_{AoA,ij/AoD,ij} = \frac{1}{2}\left|\begin{pmatrix} \sin(\theta_i)\cos(\varphi_i) \\ \sin(\theta_i)\sin(\varphi_i) \\ \cos(\theta_i) \end{pmatrix} - \begin{pmatrix} \sin(\theta_j)\cos(\varphi_j) \\ \sin(\theta_j)\sin(\varphi_j) \\ \cos(\theta_j) \end{pmatrix}\right| \quad (10)$$

Modified Fuzzy C-means algorithm (MFCM)

FCM algorithm

The object function of FCM is

$$J_m = \sum_{i=1}^{N}\sum_{j=1}^{C} u_{ij}^2 \cdot \|x_i - c_j\|^2 \quad (1)$$

$$\sum_{j=1}^{C} u_{ij} = 1,$$

Apply the method of Lagrange multipliers

$$L_{J_m} = \sum_{i=1}^{N}\sum_{j=1}^{C} u_{ij}^2 \cdot \|x_i - c_j\|^2 + \lambda(\sum_{j=1}^{C} u_{ic} - 1) \quad (2)$$

$$\frac{\partial L_{J_m}}{\partial \lambda} = (\sum_{j=1}^{C} u_{ij} - 1) = 0 \quad (3)$$

Calculate partial gradient

$$\frac{\partial L_{J_m}}{\partial u_{ij}} = (\sum_{i=1}^{N}\sum_{j=1}^{C} m(u_{ij})^{m-1} \|x_i - c_j\|^2 - \lambda) = 0 \quad (4)$$

$$\frac{\partial L_{J_m}}{\partial c_j} = (\sum_{i=1}^{N}\sum_{j=1}^{C} u_{ij}{}^m x_i - c_j \sum_{i=1}^{n} u_{ij}{}^m) = 0 \quad (5)$$

$$\frac{\partial L_{J_m}}{\partial \lambda} = (\sum_{j=1}^{C} u_{ij} - 1) = 0 \quad (3)$$

$$\frac{\partial L_{J_m}}{\partial u_{ij}} = (\sum_{i=1}^{N}\sum_{j=1}^{C} m(u_{ij})^{m-1} \left\|x_i - c_j\right\|^2 - \lambda) = 0 \quad (4)$$

$$\frac{\partial L_{J_m}}{\partial c_j} = (\sum_{i=1}^{N}\sum_{j=1}^{C} {u_{ij}}^{m} x_i - c_j \sum_{i=1}^{n} {u_{ij}}^{m}) = 0 \quad (5)$$

$$\Rightarrow \quad u_{ij} = \frac{1}{\sum_{k=1}^{C} (\frac{\|x_i - c_j\|}{\|x_i - c_k\|})^{\frac{2}{m-1}}} \quad (6)$$

$$\Rightarrow \quad c_j = \frac{\sum_{i=1}^{N} {u_{ij}}^{m} \cdot x_i}{\sum_{i=1}^{N} {u_{ij}}^{m}} \quad (7)$$

Main idea of FCM:

1.Initialize membership belief matrix u or centrods c
2. Iterate with Eq.(6) and Eq.(7)
3. Stop when u and c are not change

Christial et al. “Clustering of MIMO channel parameters – performance comparison
”

introduced FCM into clustering MPCs:

$$J_m = \sum_{i=1}^{N} \sum_{j=1}^{C} u_{ij} \cdot P_i \cdot MCD(x_i, c_j)$$

$$u_{ij} = \frac{1}{\sum_{k=1}^{C} \left(\frac{\|x_i - c_j\|}{\|x_i - c_k\|} \right)^{\frac{2}{m-1}}}$$

$$c_j = \frac{\sum_{i=1}^{N} {u_{ij}}^m \cdot x_i}{\sum_{i=1}^{N} {u_{ij}}^m}$$

$$u_{ij} = \frac{1}{\sum_{k=1}^{C} \left(\frac{MCD(x_i, c_j)}{MCD(x_i, c_j)} \right)^{\frac{2}{m-1}}}$$

$$c_j = \frac{\sum_{i=1}^{N} {u_{ij}}^m \cdot x_i}{\sum_{i=1}^{N} {u_{ij}}^m}$$

$$\frac{\partial L_{J_m}}{\partial c_j} = \left(\sum_{i=1}^{N} \sum_{j=1}^{C} {u_{ij}}^m x_i - c_j \sum_{i=1}^{n} {u_{ij}}^m \right) = 0$$

$$c_j = \frac{\sum_{i=1}^{N} {u_{ij}}^m \cdot x_i}{\sum_{i=1}^{N} {u_{ij}}^m}$$

Modification proposed in my paper

$$J_m = \sum_{i=1}^{N} \sum_{j=1}^{C} u_{ij}^m \cdot P_i \cdot \|M(x_i) - M(c_j)\|^2$$

Mapping function:

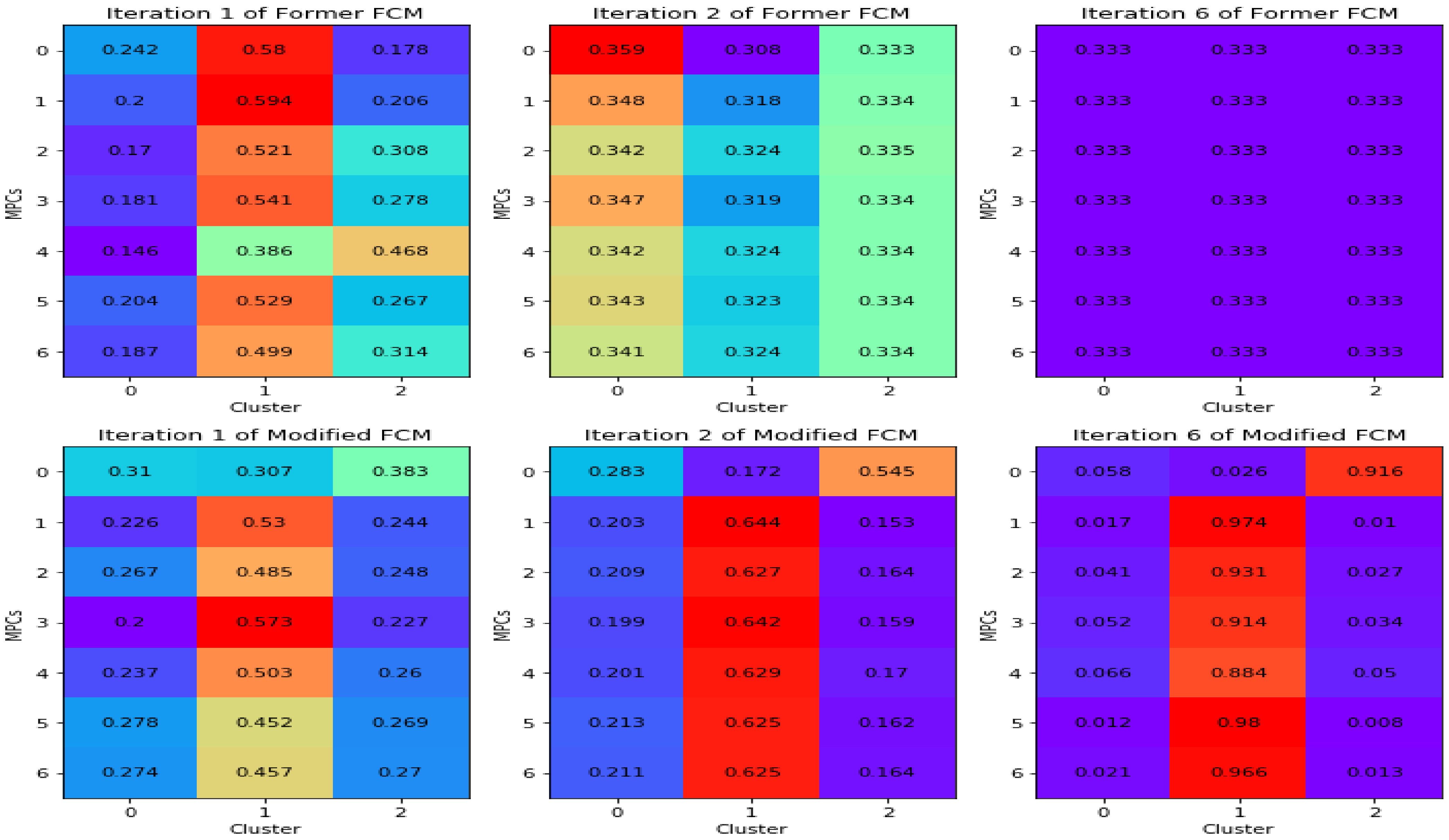
$$M(x) = \begin{bmatrix} \tau \\ \sin\varphi_{AoA} \cdot \cos\theta_{AoA} \\ \sin\varphi_{AoA} \cdot \sin\theta_{AoA} \\ \cos\varphi_{AoA} \\ \sin\varphi_{DoA} \cdot \cos\theta_{DoA} \\ \sin\varphi_{DoA} \cdot \sin\theta_{DoA} \\ \cos\varphi_{DoA} \end{bmatrix}$$

$$u_{ij} = \frac{1}{\sum_{k=1}^{C} \left(\frac{MCD(x_i, c_j)}{MCD(x_i, c_j)}\right)^{\frac{2}{m-1}}}$$

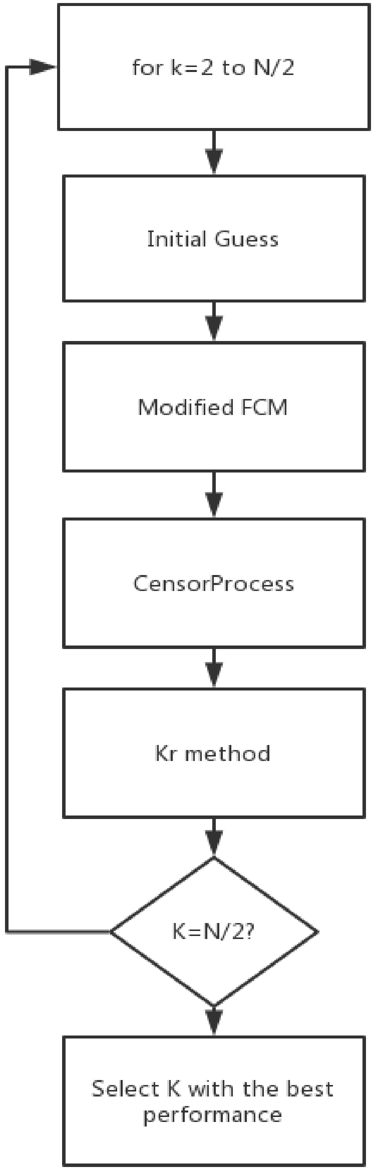
$$M(c_j) = \frac{\sum_{i=1}^{N} u_{ij}^m \cdot P_i \cdot M(x_i)}{\sum_{i=1}^{N} u_{ij}^m \cdot P_i}$$

$$\|M(x_i) - M(c_j)\| = MCD(x_i, c_j)$$

results


Iteration 1 of Former FCM
MPCs
Cluster
0 1 2
0: 0.242 0.58 0.178
1: 0.2 0.594 0.206
2: 0.17 0.521 0.308
3: 0.181 0.541 0.278
4: 0.146 0.386 0.468
5: 0.204 0.529 0.267
6: 0.187 0.499 0.314
Iteration 2 of Former FCM
MPCs
Cluster
0 1 2
0: 0.359 0.308 0.333
1: 0.348 0.318 0.334
2: 0.342 0.324 0.335
3: 0.347 0.319 0.334
4: 0.342 0.324 0.334
5: 0.343 0.323 0.334
6: 0.341 0.324 0.334
Iteration 6 of Former FCM
MPCs
Cluster
0 1 2
0: 0.333 0.333 0.333
1: 0.333 0.333 0.333
2: 0.333 0.333 0.333
3: 0.333 0.333 0.333
4: 0.333 0.333 0.333
5: 0.333 0.333 0.333
6: 0.333 0.333 0.333
Iteration 1 of Modified FCM
MPCs
Cluster
0 1 2
0: 0.31 0.307 0.383
1: 0.226 0.53 0.244
2: 0.267 0.485 0.248
3: 0.2 0.573 0.227
4: 0.237 0.503 0.26
5: 0.278 0.452 0.269
6: 0.274 0.457 0.27
Iteration 2 of Modified FCM
MPCs
Cluster
0 1 2
0: 0.283 0.172 0.545
1: 0.203 0.644 0.153
2: 0.209 0.627 0.164
3: 0.199 0.642 0.159
4: 0.201 0.629 0.17
5: 0.213 0.625 0.162
6: 0.211 0.625 0.164
Iteration 6 of Modified FCM
MPCs
Cluster
0 1 2
0: 0.058 0.026 0.916
1: 0.017 0.974 0.01
2: 0.041 0.931 0.027
3: 0.052 0.914 0.034
4: 0.066 0.884 0.05
5: 0.012 0.98 0.008
6: 0.021 0.966 0.013

Clustering Framework based on MFCM

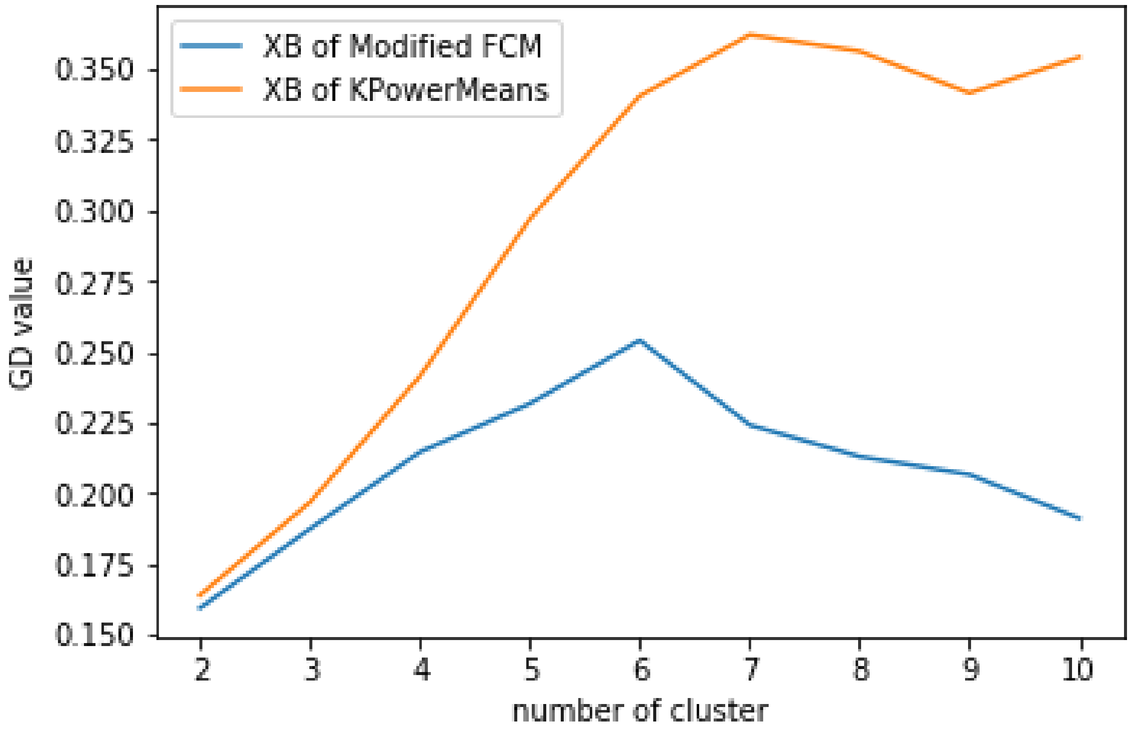


InitialGuess: generating the Centroids
Firstly select a MPC with the strongest power
Select following MPCs having maximum distance to the Centords

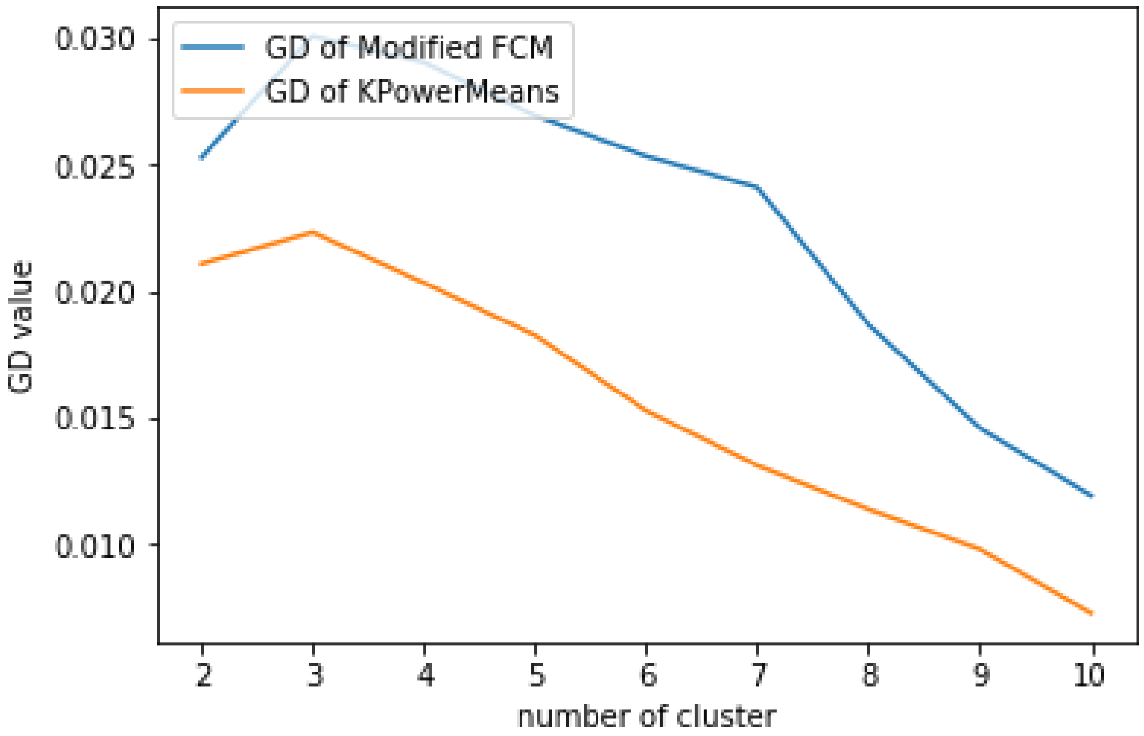
Censor Process : delete MPCs that tend to be noise
Threshold e
Allocate MPC to a certain cluster if its membership belief > e
Delete the MPC doesn't belong to any cluster

Kr method: a method to assess the clustering performance
Proposed by Mota et al. "Estimation of the Number of Clusters in Multipath Radio Channel Data Sets"

Comparison with KPowerMeans Framework



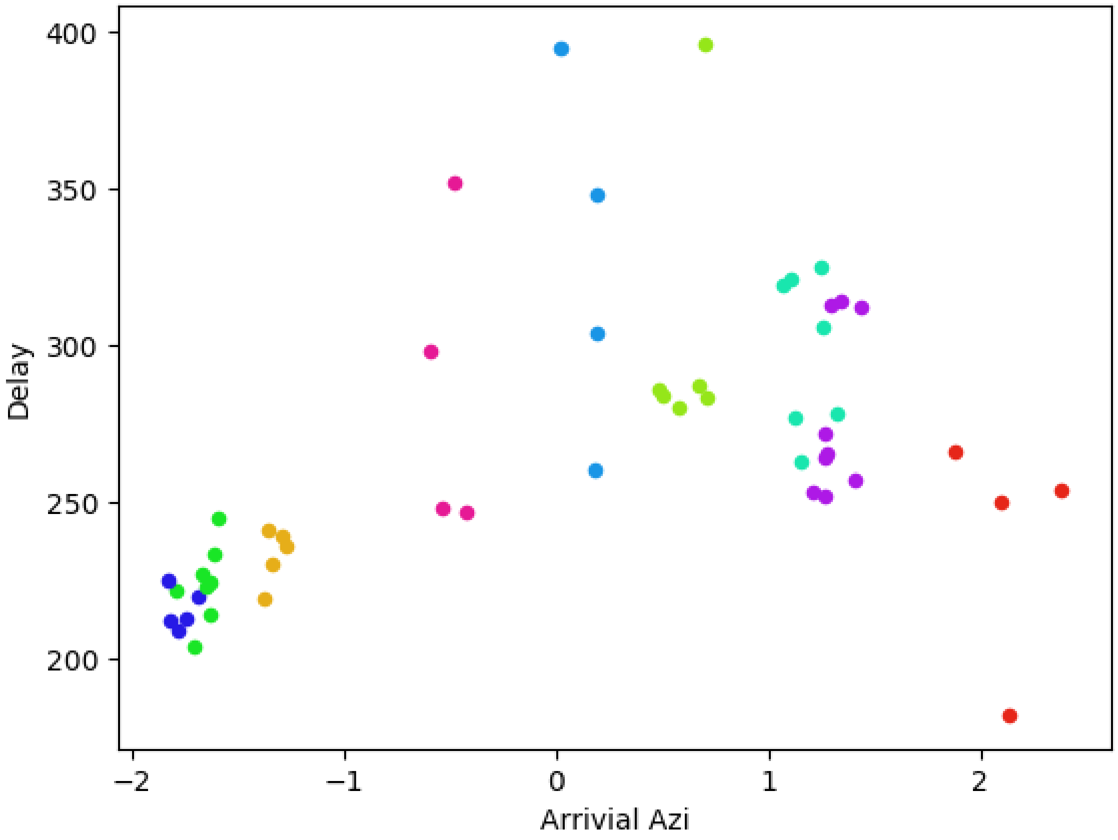
Lower XB better clustering



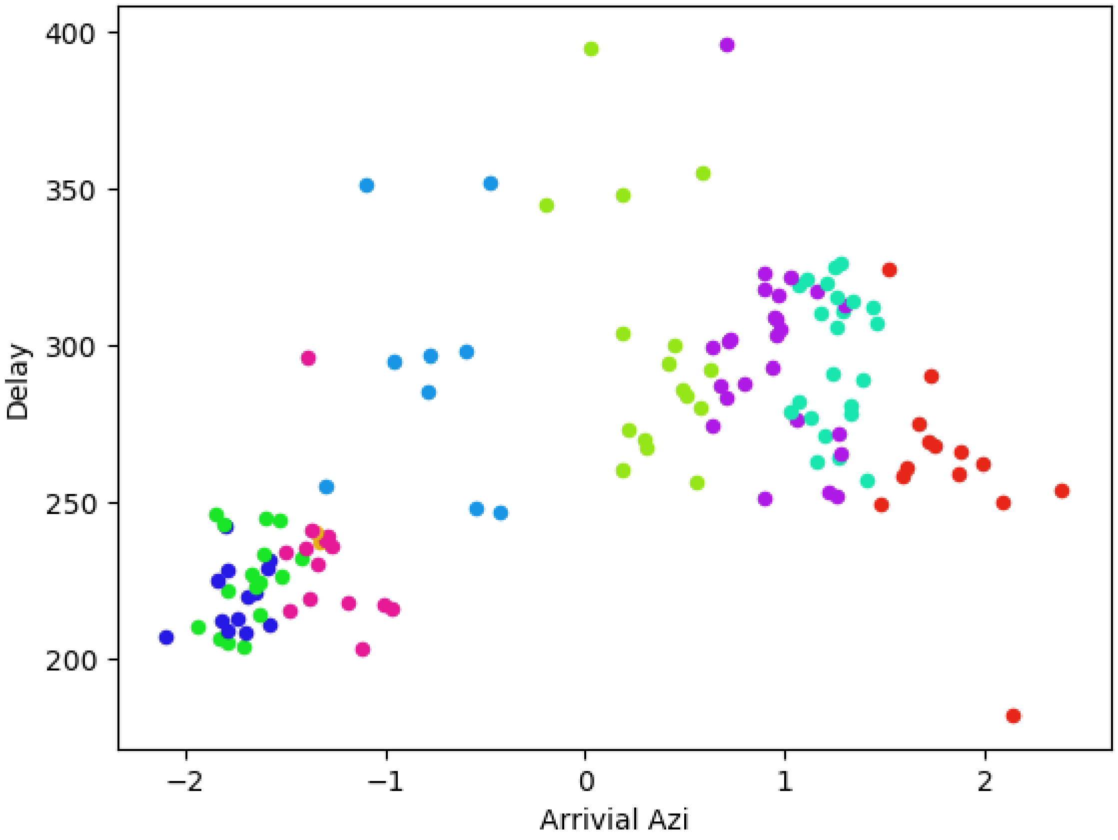
Higher GD better clustering

Average value of 300 snapshots

Comparison with KPowerMeans Framework

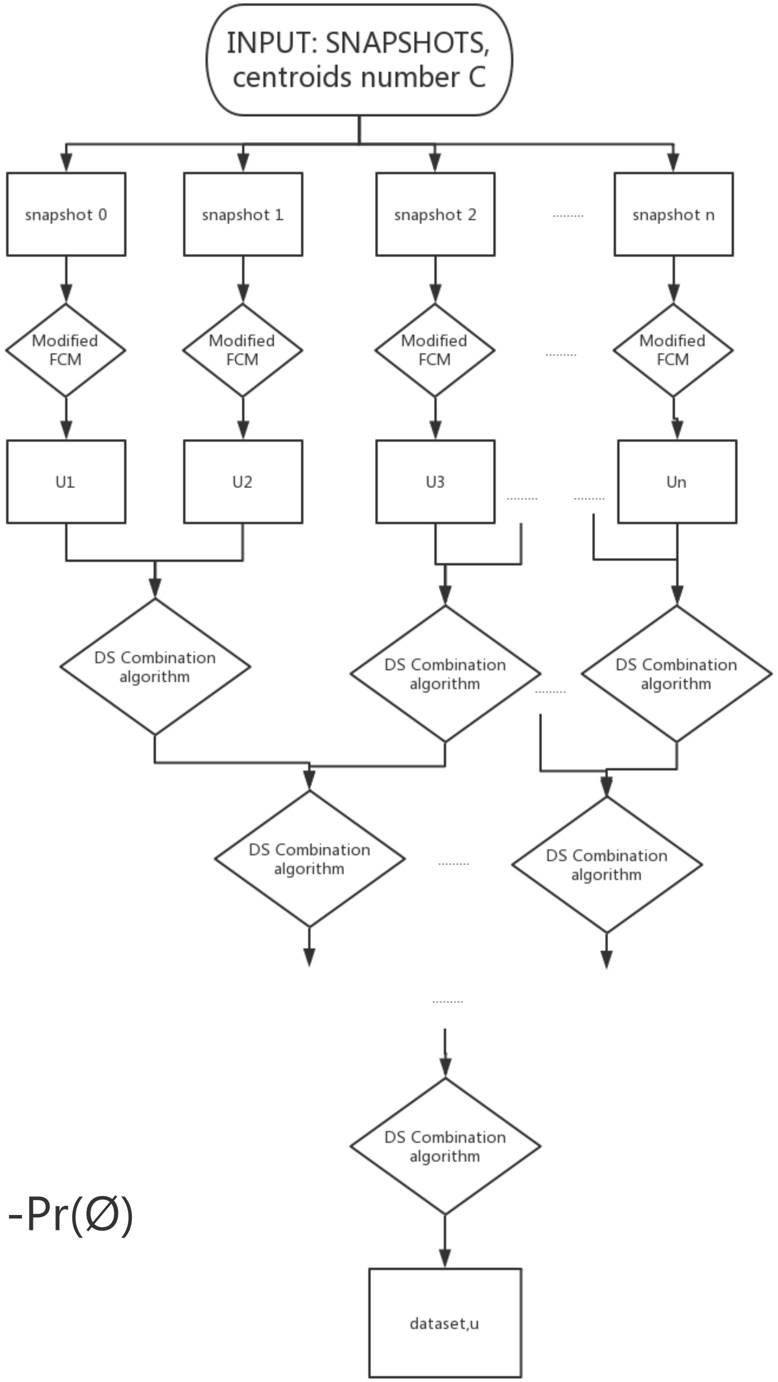


MFCM result



KPowerMeans result

Fusion Modified FCM (FMFCM)



Dempster-Shafer combination rule

$$k = \sum_{B \cap C = \varnothing} m_1(B) m_2(C)$$

$$m(\mathrm{A}) = \frac{1}{1-k} \sum_{B \cap C = A} m_1(B) m_2(C)$$

Simple example:

two sets {a:0.7,b:0.3} {a:0.6,b:0.4}
The process of D-S combination
Pr(a)=0.7*0.6=0.42
Pr(b)=0.3*0.4=0.12
Pr(Ø)=0.7*0.4+0.3*0.6=0.46
Then nomalize the Pr(a) and Pr(b) by dividing 1-Pr(Ø)
Pr(a)=0.42/(1-0.46)=0.78
Pr(b)=0.12/(1-0.46)=0.22

Results of FMFCM

	0	1
0	0.827	0.173
1	0.065	0.935
2	0.023	0.977
3	0.097	0.903
4	0.046	0.954
5	0.089	0.911
6	0.017	0.983
7	0.028	0.972
8	0.071	0.929
9	0.008	0.992

Format Resize Ba

	0	1
0	0.952	0.048
1	0.017	0.983
2	0.044	0.956
3	0.047	0.953
4	0.076	0.924
5	0.021	0.979
6	0.030	0.970
7	0.045	0.955
8	0.007	0.993
9	0.031	0.969

Format Resize Bac

	0	1
0	0.976	0.024
1	0.076	0.924
2	0.023	0.977
3	0.089	0.911
4	0.066	0.934
5	0.096	0.904
6	0.019	0.981
7	0.030	0.970
8	0.047	0.953
9	0.033	0.967

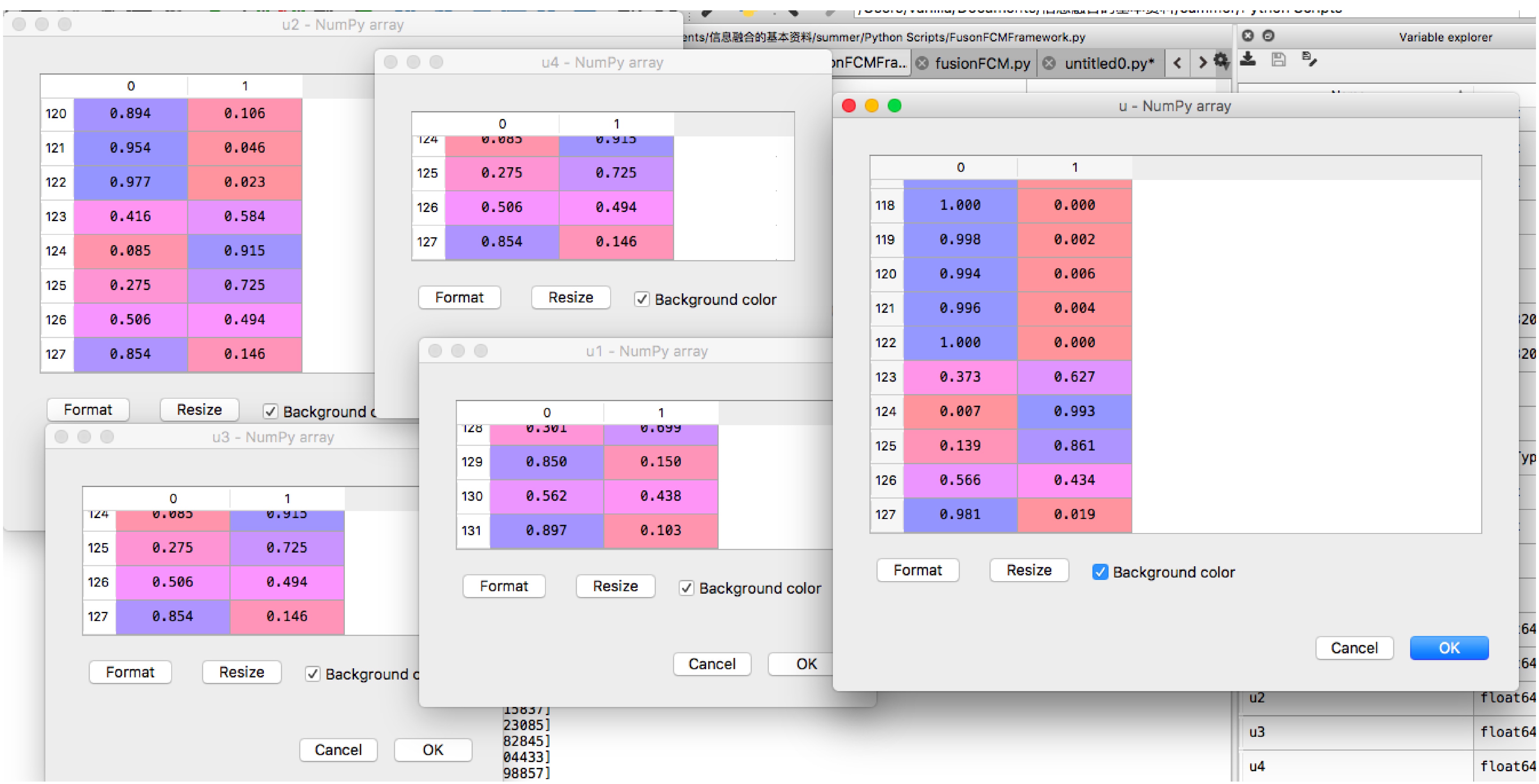
Format Resize Bac

	0	1
0	0.677	0.323
1	0.089	0.911
2	0.038	0.962
3	0.026	0.974
4	0.041	0.959
5	0.060	0.940
6	0.033	0.967
7	0.032	0.968
8	0.037	0.963
9	0.020	0.980

Format Resize

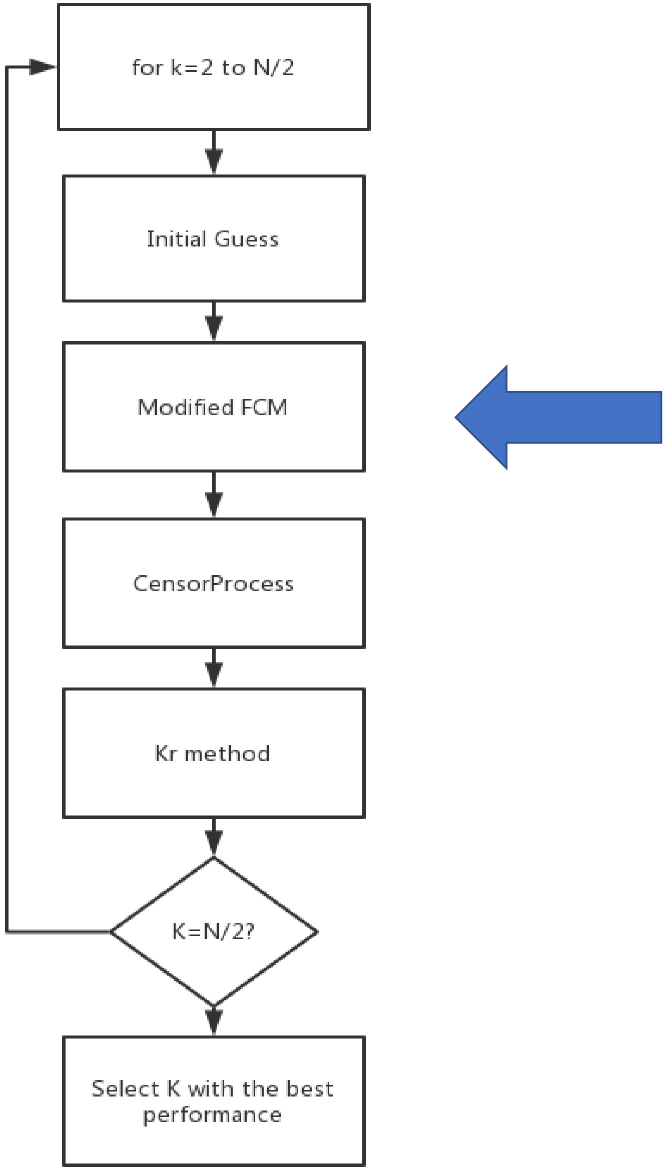
	0	1
0	0.966	0.034
1	0.001	0.999
2	0.005	0.995
3	0.002	0.998
4	0.018	0.982
5	0.003	0.997
6	0.007	0.993
7	0.004	0.996
8	0.002	0.998
9	0.006	0.994

Format Resize



Noise won't be enhanced

Clustering algorithm based on FMFCM



Replace this term with FMFCM

Thank you!